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SINUOUS COURSES
AND THE
AUTOMATIC COURSE INDICATOR
FOR NAVAL WARFARE

BY

LINDELL T. BATES

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SINUOUS COURSES
AND THE
AUTOMATIC COURSE INDICATOR
FOR NAVAL WARFARE

BY

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Printed and made public in accordance with a Resolution of the Executive Committee of the Submarine Defense Association, voted at a meeting held at 141 Broadway, on November 15, 1918.

This book is a revised reprint of a series of pamphlets published by the Submarine Defense Association, entitled,

> "Manoeuvering as a Defense Against Attack by Submarines. The Automatic Course Indicator,"

by Lindell T. Bates. The first of the series was dated November 24th, 1917. Copyrights were granted in 1917 and 1918 on pamphlets of this series.

The Automatic Course Indicator has been granted United States Patent Number 1,261,682. Application was filed on October 1st, 1917, and the Patent was issued and published by the Patent Office on April 2nd, 1918.

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INTRODUCTION

When it became necessary to study and develop the art of protecting merchant ships from German submarines, it was found important to make the most of the facts that every time a torpedo was discharged but did not hit, it meant not alone that the "target vessel" had escaped injury, but also that the submarine involved had lost a considerable part of its power of attack. The sooner the supply of torpedoes ran low the more frequently it became necessary for the submarine to return to its base through dangerous waters. Accordingly, soon after the German submarine warfare on merchant ships began, the British Admiralty took up—later to be followed by the U. S. Navy Department—the development of the art of zigzagging, for it presently appeared that a new art was involved. Successful zigzagging was found to mean much more than an occasional change in the ship's course. After the best of plans had been laid out, there was the personal equation to be considered—the risk that care in the carrying out of orders would be relaxed when the danger became an old story.

To meet the various conditions of this problem and to further perfect precautionary manoeuvers, Mr. Lindell T. Bates invented the Automatic Course Indicator. It is designed to enable vessels to steer sinuous spiral courses, affording greater safety than Zigzags, permitting more speed to be maintained and carrying a vessel further towards port. Model No. 1 of this new navigating instrument has been installed on a United States naval vessel assigned for a year by the Navy Department to the Submarine Defense Association for experimental purposes. Demonstrations have been conducted under various conditions and have shown the correctness of the novel principles involved. The Association has been informed of favorable reports by naval and military authorities of the United States, Great Britain, and other official bodies and naval men. The instrument was invented and perfected for anti-submarine use on merchant ships, but its scope has since been found to be much broader. Invitations have been extended by the navies of two of the Great Powers to equip warships with this device, so that the changes in naval tactics against hostile fleets and coast defenses, which it makes possible, may be determined. For this purpose instruments for use both with the magnetic and gyroscopic repeater compass are now being constructed by the inventor, at one of the largest American electrical plants, so as to ensure the greatest mechanical precision and time accuracy.

The technical staff of the Association has been acquainted with practically all proposed anti-submarine devices, not only those submitted to the Association, but also those in the files of British and American shipping companies, the Naval Consulting Board and the U. S. Shipping Board, courteously opened to it. On November 15th, 1918, the Executive Committee by unanimous vote congratulated Mr. Bates upon his Automatic Course Indicator, "which the Committee is convinced will more than any other invention of the war time aid submarine defense and profoundly affect coast defense, armament and naval tactics."

LUCIUS H. BEERS,
Chairman of the Association.

November 20, 1918.

SINUOUS COURSES AND THE AUTOMATIC COURSE INDICATOR FOR NAVAL WARFARE

BY

LINDELL T. BATES

1. THE SUBMARINE DANGER-ZONE

This exposition considers primarily the question of irregular courses in precautionary and battle manoeuvers against attack by submarines. Particular attention is paid to the defense of merchant vessels, for this has proved the vital naval problem of the war. A less extended review is made also of the effect of such manoeuver tactics in contests between war vessels and between these and coast defenses. Course scouting manoeuvers are incidentally treated.

In order to understand the value of manoeuvering as a means of defense for a surface vessel against torpedo and gun fire attack by submarines, it is necessary as a preliminary to state in detail certain factors of the present submarine warfare; "present" being the fall of 1918.

The submarine danger-zone at first embraced the waters immediately adjacent to the Allied coasts only. This was the zone in which in February, 1917, the Germans stated that they would sink all vessels at sight. It has been steadily enlarged until, in November, 1917, even the waters near the Azores and Greece were included. In 1918 it was extended to the Cape Verde Islands, and during this summer the German U-boats have been sinking vessels off New York Harbor. The submarine danger-zone is therefore now ocean-wide. The approaches to the Irish coast are particularly hazardous, as are other places where trade routes intersect or converge, such as the Straits of Gibraltar. At present, hostile U-boats are most likely to be met in the Irish Sea and English Channel, although certain portions of the danger-zone have been protected by nets and mines against submarine passage. Thirty per cent. of the shipping losses, according to Sir Eric Geddes, occur in the Mediterranean. He adds:

> "During the first months of the unrestricted submarine war 50 per cent. of the losses occurred more than 50 miles from land and only 21 per cent. within 10 miles of shore. To-day the losses outside the 50-mile line have fallen to 1 per cent., while the losses close to land have risen to 61 per cent." (Speech of Sir Eric Geddes, House of Commons, March 4, 1918, New York "Times," March 7, 1918, pages 1, 2.)

2. THE GERMAN U-BOATS

The German submarines which have caused the greater part of the losses are 214 feet in length, 20 feet in beam and of 900 tons submerged displacement. Submarines built in the current year and in the latter part of 1917 are over 300 feet in length and over 1,000 tons in submerged displacement. The older type have a surface speed of from 16 to 18 knots an hour, and when submerged can maintain 10 knots for about three hours. The later U-boats can attain 20 knots an hour on the surface and probably about 12 knots submerged. According to Lieutenant-Commander Charles C. Gill, U. S. N., the newest German craft can make 14 knots an hour under water.

Submarines to-day possess only two weapons of attack, the torpedo and the naval gun. The earlier U-boats were armed with Krupp guns of 3.5-inch calibre. In 1917 the calibre was raised to 5.9-inch or 6-inch. The effective range for the 5.9-inch guns is about 6,000 yards, but attacks at 8,000 yards have taken place. The submarines carry from eight to sixteen torpedoes. Formerly torpedoes having a range of from four to seven thousand yards were used, but the Germans have contented themselves with a range of a thousand yards and have thereby been able to double the quantity of explosive carried. For one thousand yards range the torpedoes can maintain a speed of about 40 knots. The

German torpedoes are said to have somewhat deteriorated, however, in recent months. A torpedo can be fired in an initial direction away from the desired course and will shift its direction to the course for which its gyroscope is set. In an attack on merchant vessels and smaller war craft the German vessels do not resort to the multiple torpedo launch. These weapons are too valuable, and too few can be carried on a submarine to warrant firing several at the same boat, except in the case of an attack on a valuable ship or on fleet or convoy.

During the early months of the ruthless submarine warfare gun fire was frequently used by the Germans. As progressively the merchant vessels were armed, resort was thereupon more frequently made to the torpedo. Thereafter the German vessels were still more heavily armed and gun fire again came into vogue. At the present time the attack with the torpedo and with gun fire is about evenly balanced. In the attack on tankers and on vessels off the American coast recourse has been largely to gun fire. On the other hand, against convoys the torpedo alone can be of value. The naval gun is used against slower ships when no patrol boats or destroyers are at hand and when the prospective victim cannot put up a strong resistance.

3. THE ALLIED MERCHANT MARINE

Many of the potential submarine victims are slow, small, and often inadequately armed vessels. Sailing ships travel at from four to five knots an hour and small tramp steamers make only about eight knots. Ten knots is quite a respectable gait for a merchantman. Of the vessels now being delivered to the Emergency Fleet Corporation those of wood are contracted to make 10 knots an hour and those of steel 12, but the latter are expected to do only 11½ knots at sea when loaded and under ordinary conditions. The United States Government vessels contracted for later completion are to be of 14 and 16 knots. A large proportion of available merchant vessels are of less than 1,600 tons, while the new steel ships for the Emergency Fleet are to be of about 8,800 deadweight tons.

It was several months after the unrestricted submarine warfare began before a majority of even the British vessels were armed. Large numbers of French and Italian vessels are still defenseless. The American vessels engaged in transatlantic trade are mostly armed, but those traveling coastwise are not so equipped. British transports are now armed with howitzers, and a few other vessels carry 4- or 5-inch guns. Many ships carry only 3-inch guns, and a large number still have no defensive armament. It should be borne in mind that the range of a 3-inch naval gun is at most about 6,000 yards, and in order to obtain this distance the gun must be given a considerable elevation, which renders aim less accurate.

4. THE CONVOY SYSTEM

The convoy system, under which many merchant vessels travel together, with or without escort of war craft, was adopted in an extended form in June, 1917. Prior thereto single vessels were frequently escorted, but did not often travel in convoy. The entry of the United States into the great war brought the application of the convoy system to Atlantic traffic. The practice is not of recent origin. The old Hansa towns had it. In the 17th Century the Spanish fleets, which carried silver from America to Spain, were convoyed. The Genoese thus protected their merchant vessels. In the Napoleonic wars its use was common.

Merchantmen for convoy abroad assemble at Halifax, New York, Hampton Roads and other rendez-vous. Vessels proceed in groups to Great Britain and France. Convoys are used also in the North Sea and occasionally in the Mediterranean. It is not possible, however, to convoy or even to escort vessels all the time. Unfortunately, there are not enough destroyers in all the Allied forces to escort all the vessels as thoroughly as one would wish. The Allies do so with very good success in the open sea, but conditions of commerce are such that it is wholly impossible to form convoys all of whose ships are bound for the same port, or if this were possible, to discharge them expeditiously in particular ports. The consequence is that a convoy of say thirty-odd vessels that arrive off the Channel, though adequately escorted from the Western edge of the danger-zone to the entrance of the Channel, must then be split into detachments going up the Channel, going to Brest and going in the Irish Sea. Each time the convoy is subdivided, the efficiency of the escort is decreased. Moreover, vessels proceeding to a rendez-vous to form an outward-bound convoy must necessarily perform at least a part of their voyage unescorted. Vessels, then, frequently proceed alone after separating from a convoy or after the scattering incidental to being attacked.

European and American coastwise vessels and ships plying between Great Britain, France and Spain run the U-boat gauntlet alone. Ships proceeding to the Mediterranean are escorted or convoyed part way only. Transports touching at Toulon, Malta, Gibraltar, Naples, Salonica and Algiers often sail alone. Occasionally convoys proceed between Gibraltar and Italy and from Egypt. Ships returning from Great Britain and France to the United States and Canada are escorted a few hundred miles only on their journey. Vessels in the South American trade are not embraced in the convoy system nor are vessels elsewhere of a speed less than about 8 knots or more than 16 knots. The fast Cunard passenger liners, such as the *Mauretania,* are escorted a few hundred miles in their transatlantic race. It should be noted that the convoy system extends to the absolutely vital arteries of sea communication only and that many ships are without even escorts in the now ocean-wide danger zone. More mileage is covered by ships traveling alone than in convoy or with escort.

The U-boat has been virtually deprived of the naval gun as a weapon against ships in convoy, for no submarine can afford to rise to the surface

in the neighborhood of destroyers. The system has made it harder also for underwater craft to attack with the torpedo, since the submarine once sighted cannot always shake off pursuit and may be rammed, or sunk by depth bombs. Ships, however, have been picked out of a convoy and sunk by torpedo. In many cases, too, the convoy formation has not been successfully maintained, and then U-boats have attacked laggards. Massed attacks upon convoys have taken place with varying results. The Germans claim to be able to pick out one or two vessels from each merchant ship convoy, but convoys of transports from the United States to Europe have been remarkably free from loss. It is true, however, that about nine destroyers are used to convoy three or four transports and that U-boats cannot pierce the cordon. In the Mediterranean, where there is a greater shortage of destroyers available for such service, there have been most serious losses in convoyed and escorted vessels. A U-boat in the Mediterranean was able, it was said, to sink four steamers belonging to one group. In mid-October, 1918, three ships were sunk from one convoy two days out from Liverpool. The destruction of the *Carpathia* and *Justicia*, while in convoy, illustrates the possibility of successful U-boat attack. When submarines are provided with weapons or means which enable them to pick a ship out of a convoy without the necessity for periscopic observations, then will the group system be indeed mortally vulnerable.

While the convoy system, when applicable, has succeeded in cutting ship losses materially, it is in every element a very expensive operation and the Allies would not like to look forward to carrying it on for some years. In spite of the attempt to group ships into convoys of corresponding speeds, the delays due to assembling and marshaling in transit the large groups are truly appalling. A voyage of a slow convoy from the United States to Europe takes anywhere from 18 to 28 days. A fast convoy can cross the Atlantic in about 12 days, whereas a big passenger liner alone covers the distance in six days, and most vessels so traveling would consume only about 10 days. It happens also, despite the best intent, that high-speed vessels are compelled to steam with slow ones. The yearly carrying capacity or effective tonnage crossing the Atlantic in convoy is thereby cut down seriously. Furthermore, mishaps are frequent. The number of marine accidents within the last year, due in a large measure to the dangers incident to the convoy system, has risen seriously. Vessels often drop out of a convoy on one pretext or another to avoid the incident vexations. In order to keep the vessels of different classes at certain relative positions their engineers must frequently change the speed of the engines. The practice of constantly changing speeds is very harmful to the mechanisms and causes a waste of coal and oil fuel. According to the London "Times" of April 9, 1918, merchant ships had then to remain half again as long as was necessary in harbors because it was not possible to get cargoes unloaded rapidly enough. A well known shipping member of Parliament compiled figures for thirty trips of his steamers and found that through delays fully twenty-five per cent. of the available time for each ship was lost.

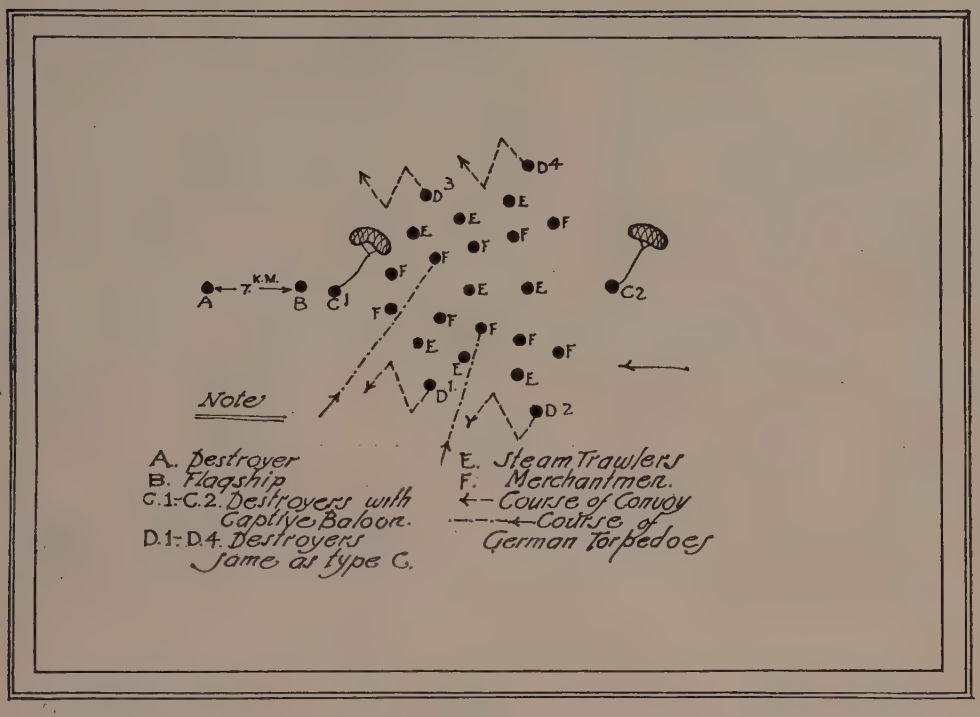


Figure 1
Typical Convoy Formation in the North Sea

Various convoying methods are in vogue, depending upon the importance, size, and number of vessels and other factors. There are convoys of merchantmen and transports. There are fast, medium and slow convoys. In the Atlantic twenty or more ships proceed in a group. In the North Sea the number is usually smaller. In the former case destroyers and cruisers escort the vessels, in the latter trawlers are added. Convoys to England proceed usually in formation of three or more columns, each ship separated about five hundred yards from its neighbor ahead and from those on the sides. Destroyers protect the wings and cruisers the head of the formation. The "Algemeen Handelsblat," of Amsterdam, in its issue of January 19, 1918, has well described how the Allies convoy vessels in the North Sea. Figure 1 shows a convoy of 10 merchantmen sailing between England and Norway. It should be noted that the merchant ships are placed in echelon or inverted V midway between line abreast and line ahead formation.

> "In front of the convoy, at least three or four nautical miles in front of it steams a modern destroyer (A), which is provided with a submarine receiver, which enables it to detect the sound of the screw of a submarine, inasmuch as the latter differs in a marked degree from the sound made by the screw of an ordinary steamer.
>
> "Behind the destroyer (A) follows the commander's ship (B), which is either a small cruiser of an older type or a so-called submarine destroyer,

and which directs the speed, course and formation of the convoy. After the commander's ship comes a torpedo boat destroyer of an older class (C 1). To it is attached a captive balloon. Observers stationed in this are enabled to overlook the surface of the sea to a wide extent and are also able to detect submarines to a considerable depth below the surface. At the rear of the convoy is another torpedo boat destroyer (C 2), with a captive balloon likewise attached to it. The flanks of the convoy are protected by torpedo boat destroyers of the C type, sailing in zigzag formation. Closer protection to the vessels of the convoy is afforded by the steam trawlers (E). Some of these also sail in the center of the convoy between the two echelons." ("The Nautical Gazette," March 21, 1918, page 3.)

5. THE TACTICS OF SUBMARINE ATTACK

Submarines usually form an irregular cordon near where steamer lanes intersect or converge—a system appropriately called by Commander Chester A. Nimitz, U. S. N., "the establishment of a highly intelligent mine field." In normal practice submarines attack singly the unescorted and unconvoyed merchant vessels encountered and gather into groups of two or more for attack upon a convoy. Attacks take place whenever vessels are sighted, day or night. While awaiting the arrival of victims, U-boats cruise at low speed on the surface, with periscope up, an observer at the periscope and another on the conning tower.

Submarines are able to communicate with each other by wireless when on the surface, and when submerged, across a certain space, by sound signals. They are now fitted with special microphones able to detect the presence of other craft at a considerable distance, from the sounds caused by the throb of the engines, the noise of the journal boxes, the hum or beat of the propeller, and the roar of the bow wave. The sound data obtainable indicate the presence only of another boat, but not yet with precision her course, speed or distance. Sound detection apparatus is not, however, as yet sufficiently perfected to replace the periscope as a means of obtaining data concerning the course, range and speed of an approaching vessel, although sound detectors from a land base are able to do this with reasonable accuracy. With the U-boat under way, sound detection from it is difficult, if not impossible, given the present facilities.

Upon sighting the smoke or superstructure of a vessel, or upon detecting her presence by sound, the submarine commander takes two or more observations from about the same position on the surface to determine the ship's approximate bearings and to note whether or not she is likely to come within a radius which would make attack profitable. If the vessel is found to be passing at some distance, necessitating considerable running on the surface at high speed to bring the U-boat within attacking distance, the attempt will not be made unless the ship is known to be an important one. To do so would expose the U-boat to discovery and would use up valuable oil fuel or electrical power. If the earliest observations give encouragement, the submarine, unless already ahead of the vessel on her course, takes a direction at 90° to the line of first observation and toward the vessel's route. At short intervals further surface observations are taken. From these the range, course and speed of the tar-

get are computed. A few further observations, taken under way, when the submarine is still invisible, although on the surface, are expected to give the commander sufficient information to enable him to decide upon the proper course to take to head the vessel off. The decision is usually reached while the submarine is still on the surface at a range such that the ship is visible to the submarine, but the U-boat is still invisible to the ship. This will be generally from fifteen to twenty thousand yards away. At this time the decision to attack with gun or torpedo is reached.

The battle tactics of naval gun warfare between U-boat and merchantman, destroyer or other vessel are simple. Upon reaching about an 8,000-yard range and determining more precisely the course, distance, speed and character of the victim, the U-boat takes a position, if possible, such that its own shells will hit the target but the opponent's will be unable to strike the submarine. This duel will take place at a range of anywhere from 4,000 to 8,000 yards. When the merchant vessel is found to be weakly armed the submarine may close up this interval considerably. To use the torpedo, however, to the best advantage the U-boat must manoeuver into a certain firing-position. Lieutenant Karl Pramer, of the Austrian Navy, has expressed as follows the importance of reaching a proper firing-position:

> "A natural result of the relatively slow speed of the torpedo (*i. e., compared with a projectile*) is the great importance of the data concerning the target's movements upon the hits scored. Because the data for the most part can be calculated with difficulty only, or not at all, but have to be estimated, it is most important to determine under what condition an erroneous estimate of these factors will least prejudice the scoring of hits." ("Der Torpedo und Seine Verwerdung in Kriege," Lieutenant Karl Pramer, Mitteilungen aus dem Gebiete des Seewesens, 1914, Volume 42, page 277. Translated by L. T. Bates.)

6. THE TORPEDO FIRING-POSITION

It has been found that unless the speed of a ship or her range is abnormally great the submarine stands the best chance of scoring a hit when firing the torpedo from a position slightly ahead or abeam of the vessel—a position such that the course of the vessel forms a bow angle (γ) of about 90° with the line joining the centres of the vessel and submarine. Captain Philip R. Alger, U. S. N., says:

> "There is a tremendous disadvantage in firing at a target moving away from one." ("Torpedo Firing at Moving Targets," Philip R. Alger. Proceedings of the United States Naval Institute, 1910, Volume 35, page 182.)

Alger adds:

> "While it makes very little difference if γ is somewhat less than 90° there is a great falling off in the chance of hitting if γ is even 10° greater than 90°." (Op. Cit., page 182.)

From tables prepared by this authority it appears that when γ is less than 30° the chance of scoring a hit is also very slight. In American practice γ is usually about 70°.

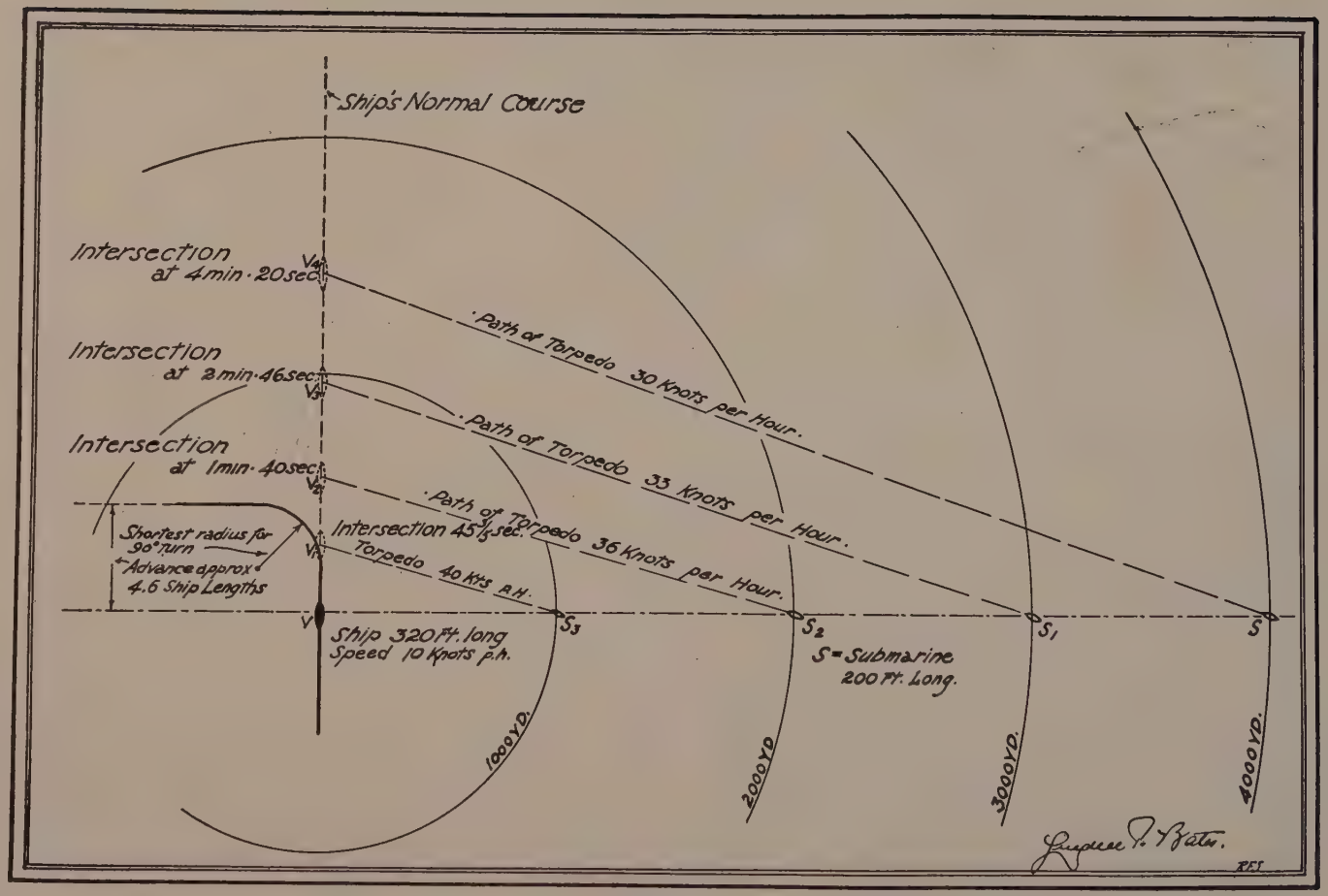

Ship's Normal Course
Intersection at 4 min. 20 sec.
Intersection at 2 min. 46 sec.
Intersection at 1 min. 40 sec.
Intersection 45½ sec.
Path of Torpedo 30 Knots per Hour.
Path of Torpedo 33 Knots per Hour.
Path of Torpedo 36 Knots per Hour.
Shortest radius for 90° turn
Advance approx 4.6 Ship Lengths
Torpedo 40 Kts A.H.
Ship 320 Ft. long
Speed 10 Knots p.h.
S = Submarine 200 Ft. Long.
1000 YD.
2000 YD.
3000 YD.
4000 YD.

Figure 2
The Path of the Torpedo When Fired at Various Ranges

In order to be at all sure of hitting the target a submarine must also fire the torpedo at close range. M. Chapuis, the eminent French naval authority, states:

> "It is impracticable to fire at moving targets at a range exceeding 1,000 meters (in exceptional cases 1,500 meters) so long as torpedo speed does not exceed 45 knots." ("Torpedo Fire at Moving Targets," M. Chapuis. Translated by Philip R. Alger. Proceedings of the United States Naval Institute, 1909, Volume 35, page 168.)

The German orders are to fire, if possible, at a range not exceeding three hundred yards. The torpedoes that sank the *Lusitania* were fired at a distance of about five hundred yards. Figure 2 illustrates torpedo firing at various ranges.

Upon securing a torpedo firing-position the chances of hitting at a thousand yards are very good, at 2,000 yards less promising and beyond 3,000 yards the hitting percentage falls off rapidly. This is confirmed by Lieutenant Commander Romeo Bernotti, of the Italian Navy, who has calculated the probable percentage of hits which can be made with a 25-knot torpedo on an 18-knot vessel 200 meters long. The table allows for an inaccuracy of plus or minus 10° in course estimate and plus or minus two knots in the estimated speed of the vessel attacked. ("The Torpedo on Capital Ships," Romeo Bernotti. Translated by Lieutenant T. Withers, Jr., U. S. N. Proceedings of the United States Naval Institute, 1914, Volume 40, page 1776.)

	Range in Meters							
Angle γ	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
30°	22%	17%	13%	9%	8%	7%	5%	3.5%
60°	38%	29%	21%	16%	12.5%	9%	8%	7%
90°	39%	23%	14%	9%	..	..	..	..
120°	14%	9%	..	..	..	..	..	..
150°	7%	..	..	..	..	..	..	..

7. THE APPROACH TO TORPEDO FIRING-POSITION

It is by no means an easy matter for a submarine to take up the desired firing-position. To have any chance of so doing, the submarine, upon discovering the presence of a vessel to be attacked must be already located within the latter's danger-area. The torpedo danger-area is defined by Commander Harry S. Knapp, U. S. N., and Lieutenant Commander George W. Logan, U. S. N., as "that space which includes all points that the torpedoes of a given vessel (*i. e., submarine*) may be expected to reach under given conditions." ("Useful Curves, Scouting and the Torpedo Danger Area," Commander H. S. Knapp, U. S. N., and Lieutenant Commander G. W. Logan, 1908, page 56.) The danger-area for a particular vessel depends upon her speed and that of the submarine and the torpedo. It therefore varies with nearly every case. The danger-area for a fast vessel is smaller than that for a ship traveling less fast. Fast vessels are less liable to submarine attack than slow ones. Figure 3 reproduces a chart published on July 19, 1917, by the New York Chamber of Commerce. It shows the percentage of sinkings by gun fire and torpedo in relation to the speed of the vessel attacked by submarine. The sinking of the *Lusitania* is practically

the only illustration of successful attack against a vessel traveling at 18 knots. Chapuis speaks of the impossibility of attacking under favorable conditions a vessel going faster than the torpedo. (Op. Cit., page 161). Alger says:

> "The faster the torpedo relative to the target, the smaller the error. Assuming target speed to be constant, an increase of 50 per cent. in torpedo speed will reduce the maximum error at the target two-thirds, an increase of 125 per cent. will reduce the error five-sixths, and an increase of 200 per cent. will reduce the error eight-ninths." (Op. Cit., p. 180.)

Furthermore, it is easier by observation to estimate correctly slow speed than fast. The speed of a target vessel should, therefore, be maintained as close to that of the torpedo as possible, so as to render the error at the target greater, and thereby increase the safety of the ship.

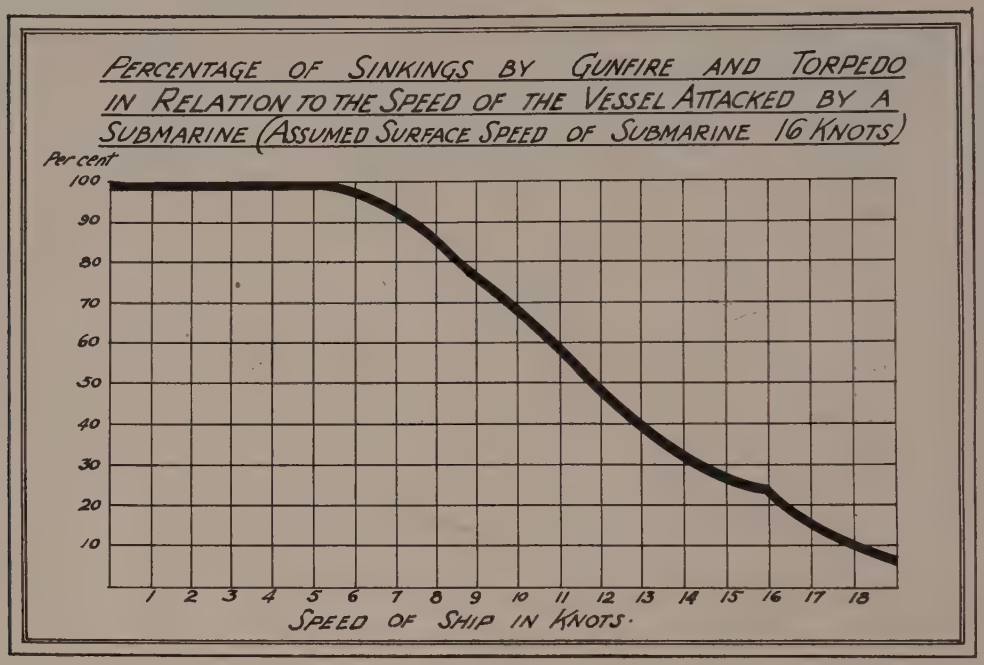


Figure 3
New York Chamber of Commerce Chart Showing the Relation of Speed to Safety

In order to reach a torpedo firing-position within a ship's danger-area a submarine must submerge when still at a considerable distance away and must proceed under water and unobserved to the station sought. At ranges within 1,000 yards, if the torpedo is fired before the vessel puts her helm over, there is practically no chance for her to avoid being hit. If, therefore, a submarine reaches the proper torpedo firing-position at close range, the ship will be hit no matter what her speed. When, therefore, the submarine reached a position abreast or slightly ahead of the *Lusitania* and only 500 yards off, no small increase in speed or possible manoeuvers could have saved her. The torpedo takes less than a minute to travel a thousand yards. It requires more than a minute

for most vessels to turn sufficiently to avoid a torpedo aimed to strike a ship at an expected meeting point. On the other hand, if the submarine is sighted at a greater distance than 1,000 yards, before or even shortly after the torpedo is fired, the vessel may escape by a quick manoeuver. It is vital, therefore, for the success of submarine attack that the U-boat reach its firing-position before discovery.

For a torpedo firing-position to be reached and a torpedo to be aimed with accuracy, a submarine captain must learn three things—the course of the vessel to be attacked, her speed and the range, that is, the distance between the submarine and the target. Given these important data, the mathematical problem for the attacking manoeuvers and the torpedo firing becomes simply the solution of triangles in which the bearings and range of the ship and U-boat, speed of the ships and torpedo and angle of torpedo fire are utilized. For the approach to torpedo firing-position, mention should also be made of a "Rule of Thumb" which is resorted to when triangulations based upon course, range and speed-estimates cannot be or are not used. If the submarine at all times navigates on a line perpendicular to that joining the two ships and towards the ship's course, it will eventually approach the target vessel, unless range or speed differences prevent. Attacks are also often made in more or less haphazard fashion, according to the impression of the U-boat commander regarding the target's course, range and speed.

8. PERISCOPIC OBSERVATIONS

To obtain the requisite data periscopic observations are still necessary. Lieutenant Commander Charles C. Gill, U. S. N., describes the approach to firing position as follows:

> "Beginning at 4,000 yards, the submarine can be expected to show about one foot of periscope and observe for a period of about thirty seconds. After this four or five successive observations will probably be taken at intervals of about one minute, the period of time that the periscope is exposed, diminishing gradually to ten or twelve seconds. In the meanwhile the submarine will have closed to about 2,000 yards and from now on only a few inches of periscope will be exposed, but at more frequent intervals, about every thirty seconds, and the length of time the periscope will be shown will decrease from ten to five seconds. At about one thousand yards the firing exposure will be made, and this will probably be for about twenty-five seconds in order to assure a well-aimed torpedo." ("Anti-Submarine Tactics," Lieutenant Commander Charles C. Gill, U. S. N., Current History, October, 1917, pages 123, 124.)

It happens, however, that a submarine may observe a vessel at a distance, determine the probable firing-position and travel submerged to the selected place without taking intermediate observations. In recent months periscopes have been very rarely sighted and it is probable that the Germans have reduced materially the number of periscopic observations necessarily taken. Lieutenant Commander Gill says that the periscope is exposed "for gradually diminishing periods of time ranging from 30 seconds down to 5 seconds, except

the last exposure for firing, which lasts about 25 seconds." ("Naval Power in the War." Lieutenant Commander Charles C. Gill, U. S. N., 1918, page 139.)

While periscopes are fitted with range-finding aids, the determination of range and also of course and speed is in practice more or less speculative. In calculating for torpedo-fire an allowance is usually made for an error of 2 knots in speed and 10° in course. Lieutenant Commander Romeo Bernotti says:

> "So we think it optimistic for the torpedo to assume a mean error of plus or minus 10° and plus or minus 2 knots in the course and speed of the enemy respectively." (Op. Cit., p. 1776.)

Figure 4

The Image seen through a Goerz German "Ring-Center Image" Periscope

Alger allows for an error of 10% in speed and 1 point (11¼°) in course. (Op. Cit., p. 149.) An experienced American submarine commander has said that through a periscope he could not tell within three hundred yards the distance of a vessel whose supposed position is about a thousand yards away. Range finders may be used upon a submarine which is on the surface, but as a matter of practice the Germans in shelling resort to "spot-firing," that is to say, they make trial shots and regulate their guns until the shots hit. In certain parts of the danger-zone, where the weather is hazy, it is exceedingly difficult to judge limits of visibility, distance of objects or to obtain an accurate range even with range finders. In the North Sea variations of 2,000 yards at a distance of 10,000 yards are noted, due to lack of definition in target vessels. On this account battle tactics, evolutions and manoeuvres are based largely on the visibility factor. In these parts of the submarine danger-zone the errors in course, speed and range estimate may be very great.

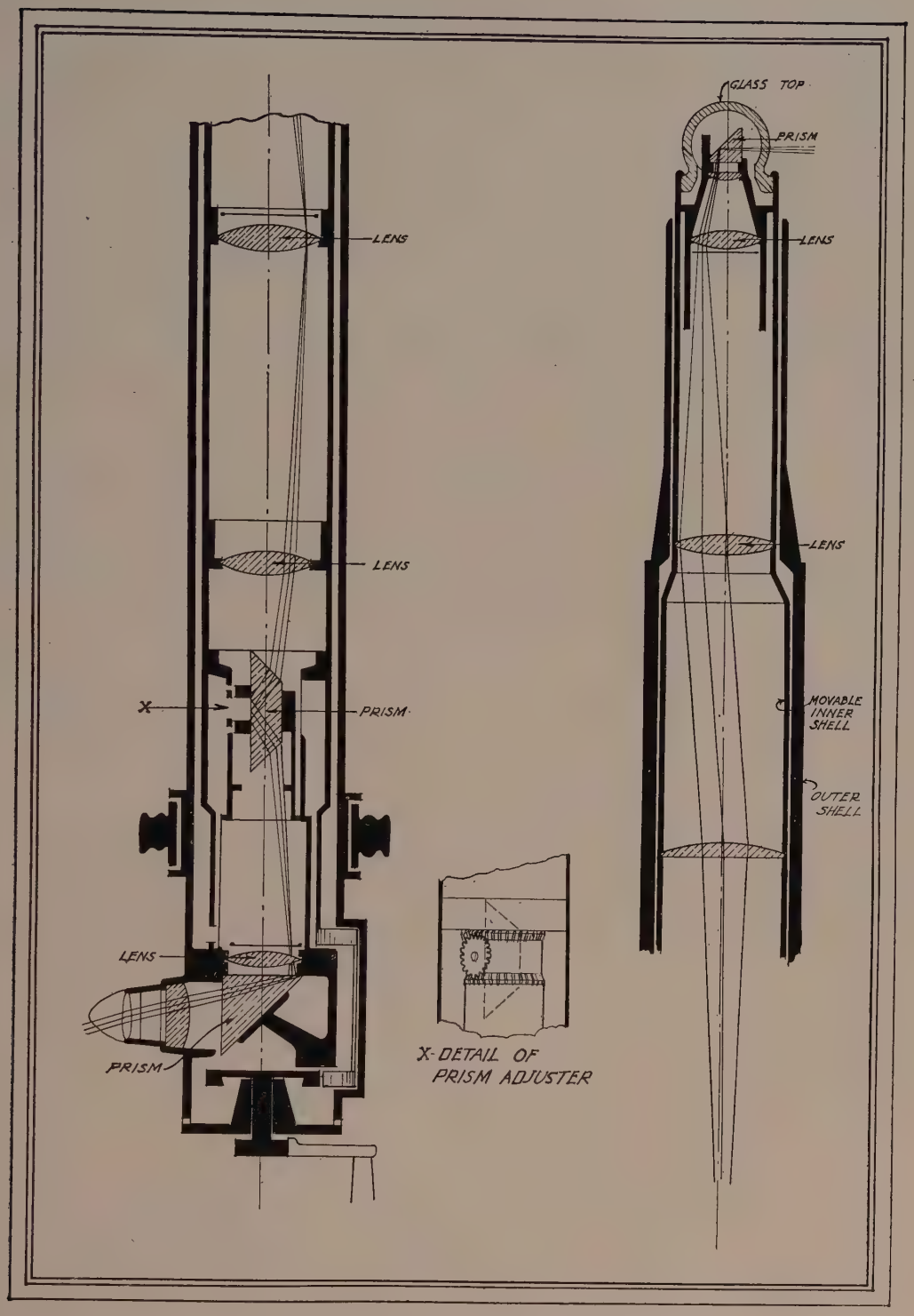


Figure 5
Goerz German Panorama Periscope with Glass Top

The mechanical features of periscopes are now well arranged for conveniences. For instance, periscopes may be rotated in any desired direction, may be elevated to about twenty feet above the observer's station, the image may be reflected upon a convenient screen, and the direction of observation may be indicated with reference to the axis of the submarine. In some instruments the entire horizon may be scanned at once. Normally periscopes enlarge the image from 1.2 to 1.5 times, but magnification 3 to 6 times is possible. The image seen through a highly perfected German Goerz "Ring-Center Image" Periscope, devised before the war, is shown in Figure 4. A Goerz Panorama Periscope, with glass top, is shown in Figure 5. German periscopes are now, however, only two inches in diameter in the part which protrudes from the water and are nickel-plated, so that a small wake is made by them and they are nearly invisible.

A leading German periscope expert, Dr. F. Weidert, has well expressed the difficulties of range-finding from a submerged U-boat:

> "Now it is already well enough known that correct range estimation with the naked eye without some means of assistance is extremely difficult and is for many people actually impossible. With one-eyed vision through an optical instrument this is even much more the case. On the other hand, precise knowledge of the range is essential for many purposes, especially for the firing of torpedoes. To unite with the periscope a range finder of sufficient base meets indeed with serious difficulties inasmuch as one cannot apply apparatus whose use will cause one to run the risk of being prematurely seen by the opponent." ("Entwicklung und Konstruktion der Underseebootesehrohr," Dr. F. Weidert, Jahrbuch der Schiffbautechnischen Gesellschaft, 1914, Vol. 15, p. 222. Translated by L. T. Bates.)

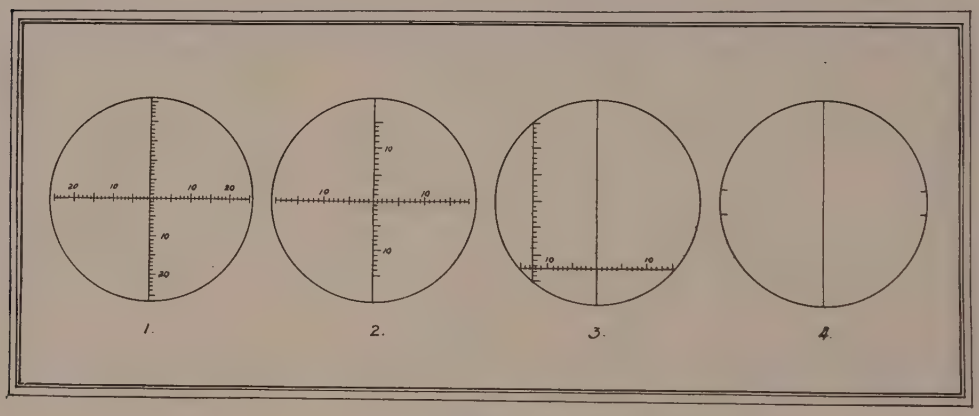


Figure 6
German Telemeter Scales

To ascertain range from periscopic observation one of the two methods alone available is to project into the eye-piece of the instrument telemeter scales or cross hairs graduated vertically and horizontally in hundredths. For example, in the Keuffel & Esser periscopes a vessel one hundred feet long measures five graduations in the scales at 1,000 yards range. Figure 6 illustrates

the telemeter scales used in the German periscopes. Several variations of this system are in use, but they are all open to the objection that the dimensions of the object must be assumed. If a projected view is seen the assumption as to the size may be very erroneous, since the length will appear shorter than it actually is. The other method, of which there are also several variations, is the double image micrometer. Figure 7 shows the latest Goerz double image micrometer range finder. Two pictures of the same object are made to cut each other in the lens, and are shifted with reference to one another until the tops of the masts, or other high parts, of a ship under observation in one picture are level with the water line in the other. The angle of shift is measured to determine the distance. This method, too, is only roughly approximate, for it has to deal with the measurement of a very small angle and it assumes the height

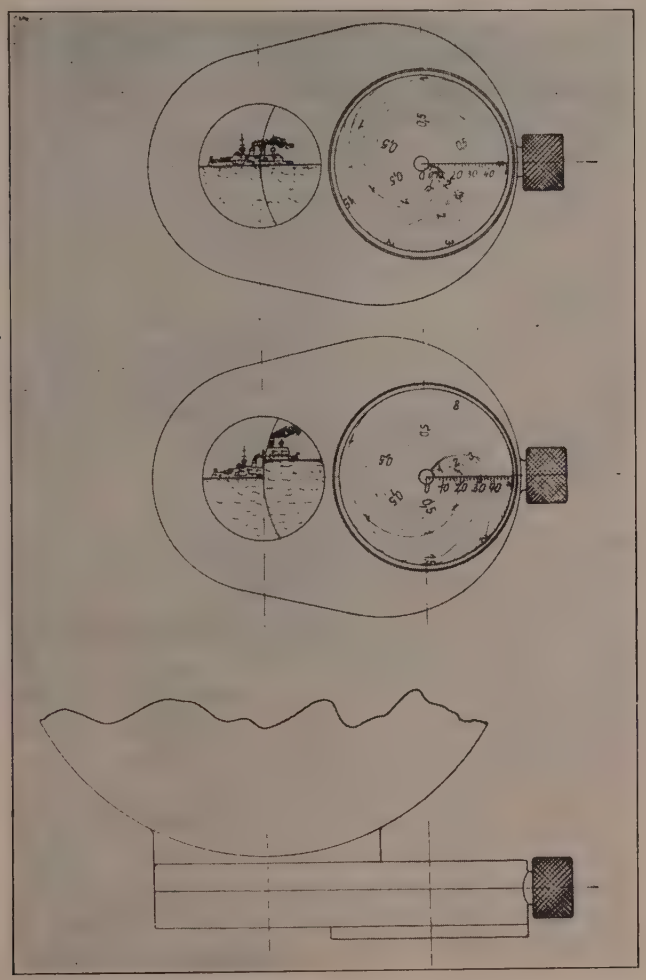


Figure 7
The Goerz German Double Image Micrometer Periscopic Range Finder

of the selected part of the vessel and uses this figure as length of base line. Owing to the limitations of the periscope, range from a submerged U-boat is estimated in view of an assumed target dimension,—length or height. As Wiedert says, "one considers oneself satisfied with the practice of determining range from the size of the image compared with a given size of the target." He also points out a further disadvantage of the available range-finding facilities:

> "All these methods have, however, the disadvantage that as a result of the movements of the ship the image seen against the scale is in constant motion, so that it requires quite some practice to correctly estimate its length." (Op. Cit., p. 224.)

In regard to the manner of calculating the course of the vessel to be attacked, the range at the various times that the vessel is observed gives an approximate indication, inasmuch as the U-boat's own course and speed are known. In the calculations of course from a submerged U-boat, visual estimate, which includes noting the perspective view of the ship and alignment of masts and funnels, plays a considerable part.

Regarding the speed estimate, Hoar says:

> "The speed of the target may be solved mechanically by measuring the angles of her image in the periscope, with respect to the course held by the submarine, at certain intervals of the time and by plotting these points on a specially constructed scale." ("The Submarine Torpedo Boat," Hoar, 1916, p. 162.)

The speed calculation so made is approximate only, since it depends for its accuracy upon that of the range calculation. The time taken by vertical parts of the vessel to pass the distance between cross-hairs in the periscope also indicates in a general way her speed. The bow wave indication is also considered on occasion.

9. THE EFFECT OF ERRORS IN COURSE, SPEED AND RANGE ESTIMATES

The effect upon the success of a submarine's manoeuver for position of an error in estimating the course, speed or range of the vessel to be attacked may be very important. As may be seen from Figure 8, an error in course-estimate of from 10° to 20°, in a direction which carries the vessel toward the U-boat, which is approaching a thousand-yard firing position, may force the submarine to remain under water, for fear of being run down or of being destroyed by gunfire or depth bombs. A similar error in course-estimate, which carries the vessel away from the submarine, will probably prevent successful attack, unless the latter can manoeuver into another firing-position. If the speed of the submarine when submerged is less than that of the vessel attacked, it will be almost impossible for the U-boat to take up a second suitable firing-position. An error in the estimated speed will not prevent the submarine from reaching a firing-position if the vessel's speed is slower than is estimated. But if the ship's speed is faster than estimated, the submarine may

lose her best opportunity to fire, since firing from a position abaft the beam of the target vessel is far less likely to succeed than firing from a position forward of the beam. The situation of a submarine which has misestimated the speed of the target is shown in Figure 9. An error in estimating correctly the range, as shown by Figure 10, may considerably diminish the chance of a submarine's manoeuvering into a firing-position. If the distance has been underestimated, inasmuch as the probabilities are much lessened for scoring a hit at a range greater than a thousand yards, the opportunity for torpedo attack may be lost. A moderate overestimation of the range will be likely, however, to bring the submarine into a more advantageous firing position. A serious overestimation, on the other hand, may expose the submarine to being rammed by the vessel attacked or to being sunk by depth bombs dropped when the vessel over-runs the U-boat.

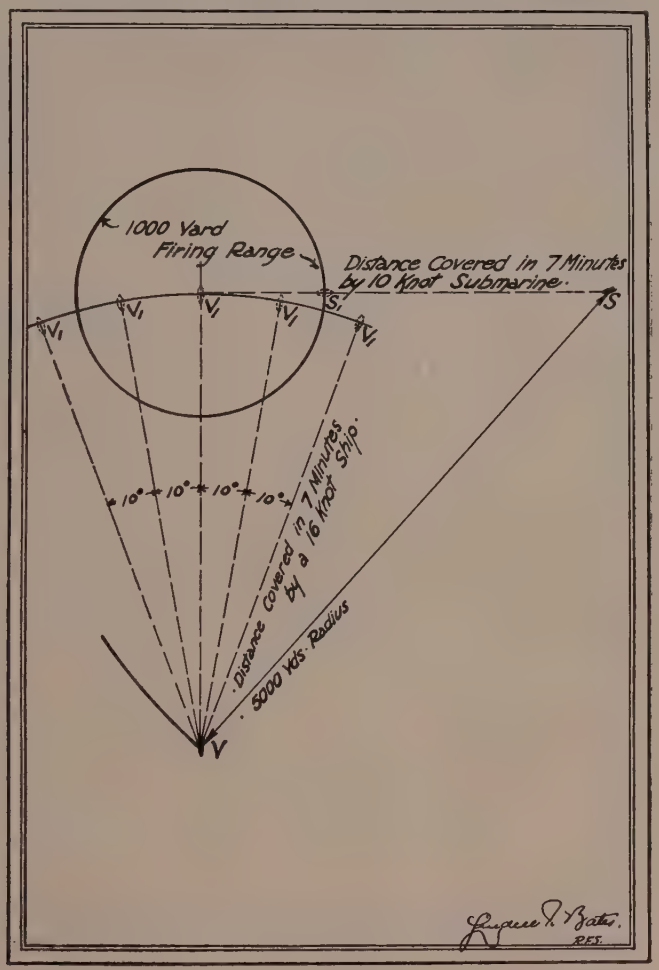


Figure 8

The Effect of an Error in Course-Estimate upon a Submarine's Manoeuver for Position

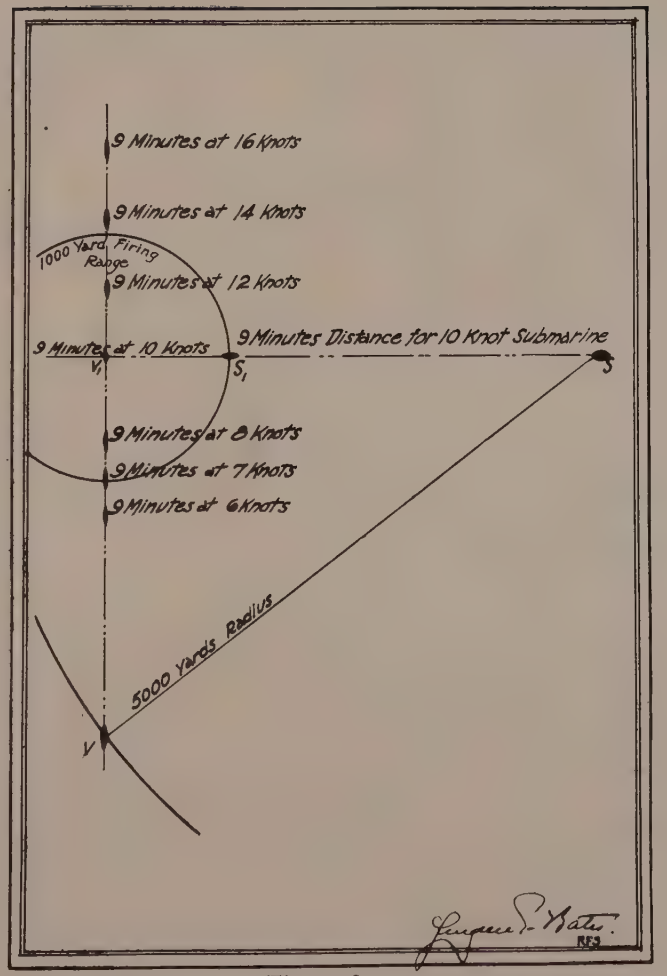

9 Minutes at 16 Knots
9 Minutes at 14 Knots
1000 Yard Firing Range
9 Minutes at 12 Knots
9 Minutes at 10 Knots
9 Minutes Distance for 10 Knot Submarine
9 Minutes at 8 Knots
9 Minutes at 7 Knots
9 Minutes at 6 Knots
5000 Yards Radius

Figure 9
The Effect of an Error in Speed-Estimate upon a Submarine's Manoeuver for Position

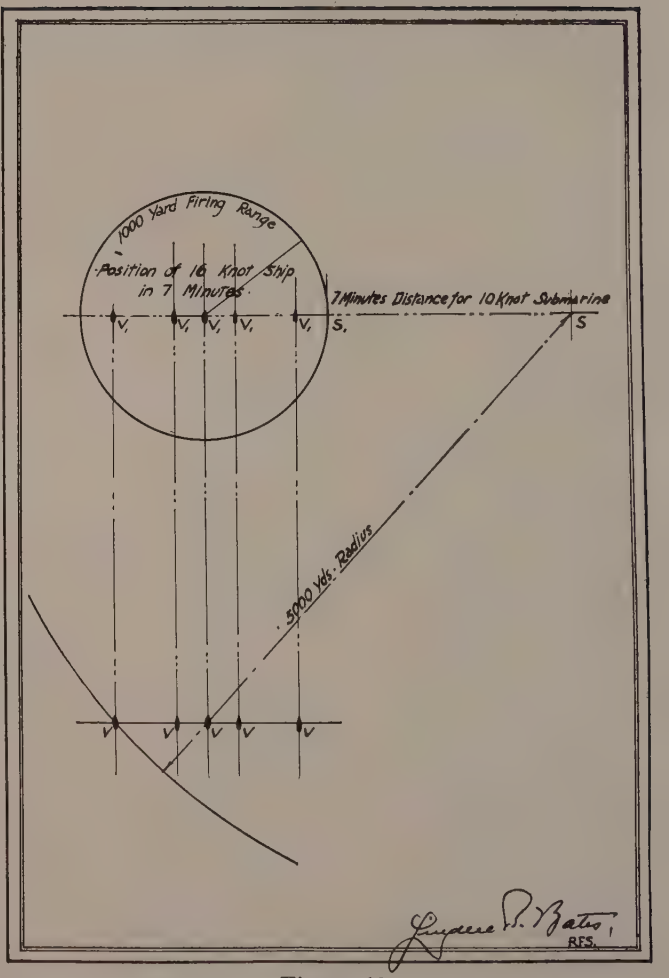


Figure 10
The Effect of an Error in Range-Estimate upon a Submarine's Manoeuver for Position

In respect also to accuracy of torpedo fire, errors in estimating the target vessel's speed, course, or range may be vital. The results of similar errors in calculations are not necessarily the same in their effect upon torpedo fire as in their effect upon the manoeuver by the submarine for position. While the error at the target resulting from a misestimation of the speed of the vessel can never be annulled, a proper selection of the moment of firing and the range will render unimportant a slight error in estimating the course of the target. This will be the case if the torpedo is launched at close range and at or slightly before the moment when the target is situated at the foot of a perpendicular let fall from the point of launching upon the supposed course of the target. If, however, the torpedo is not fired when the angle γ is about 90°, the effect of an error in the course may be added to that of an error in the speed of the target, or subtracted therefrom, according to the relative senses of the errors. On account of the independence of these errors, one cannot count upon the one error's annulling the other. The distance by which a torpedo misses a target, due to an error in the speed or course estimate, increases in direct proportion to an error in range. An overestimation of the range causes a torpedo to go wider of its mark than an underestimation.

To show just how serious a matter errors in course and speed estimate really are, Chapuis has calculated that with γ 70°, the speed of the vessel 20 knots, and the torpedo velocity 35 knots, cumulative errors of 1 knot in the estimate of the ship's speed and half a point (5 5/8°) in her course, will result in an error of 49 meters if the torpedo is fired at 1,000 meters range, 72.5 meters at 1,500, 97 meters at 2,000, and 146 meters at 3,000. Even with such small errors, inasmuch as the torpedo is aimed for the center of the ship, a vessel 100 meters long will not be hit, therefore, at over 1,000 meters range. Furthermore, an allowance for error of only one knot and of half a point may be an underallowance.

10. SHIP MANOEUVERS AGAINST SUBMARINE ATTACK

Manoeuver tactics are established by all the belligerent governments for the protection of vessels actually attacked by submarines. The instructions of the several nations to their ships are substantially the same. If the submarine is sighted forward and over a mile away, the orders are to bring the submarine astern at the highest possible speed, making for land or shallow water. If the submarine is sighted close abaft the beam, the greatest safety also lies in bringing the submarine astern. A vessel that is being pursued should get close to patrol boats as soon as possible. When a submarine has been placed astern, the new course should be a straight line so long as the position of the submarine is known. When its position is lost, irregular courses should be steered in a direction away from the place where the submarine was last sighted. If the submarine is sighted close forward of the beam, the greatest safety lies in steering directly for the submarine. The submarine will then be likely to submerge deeply, and if not, it will keep its periscope above water so as to see the

manoeuver. In any case, the merchant ship will present the smallest target, and if a torpedo is fired a skillful use of the helm may just possibly enable the ship to avoid it. In case a vessel is outranged by the guns of a submarine, the official advice is to zigzag until the submarine is within range of the ship's guns. It is extremely difficult for a submarine to hit at long range a vessel that is making short and irregular changes in course.

If a vessel has a choice in the direction of attempted escape, she is required to steam into the wind and sea, so that the U-boat may be unable to resort to gunfire. The ship's speed may then enable her to escape, perhaps with the aid of a smoke screen. Steaming down the wind allows a submarine a greater chance for successful attack. In all cases, the battle manoeuvers for a merchant vessel aim to handle her in such a way as will secure escape, and, if that is impossible, then as will facilitate her gunfire and at the same time expose the smallest target to a torpedo. Steering directly toward a submarine has the advantage of disconcerting its attack, since the U-boat must then itself manoeuver to avoid being rammed or being sunk by depth bombs. Turning away gives a ship the advantage of lessened danger of torpedo and gunfire attack by increasing the range, and her screw current may possibly deflect a torpedo.

The foregoing manoeuvers are established for use in case the U-boat is sighted. It frequently happens, however, that only the wake of a torpedo is seen. In this case the authorities direct that as soon as possible the ship be placed on a course parallel to the wake of the torpedo. In all cases where submarines are sighted at a distance of 1,000 yards or less the probability that a torpedo has already been fired is very great. A sharp lookout should be kept for its typical wake and the ship manoeuvered, if possible, to avoid the oncoming torpedo.

In order to prevent a submarine from taking up a suitable torpedo or gun firing-position and from aiming accurately, the United States and co-belligerent powers have insisted that vessels perform precautionary Zigzag manoeuvres. The instructions of the allied governments to their merchant vesses, both those proceeding in convoy and singly, require them to perform special manoeuvres even before the submarine is sighted. It has been the consensus of opinion that frequent changes in course are one of the most effective ways of avoiding attack by U-boats. The submarines have difficulty in getting into position to fire a torpedo at vessels zigzagging. Even after getting into position the torpedo will miss the ship if the vessel has time to change her course before it strikes. It is important that zigzagging be done in an irregular manner as otherwise the submarine may predict the future position of a ship and get into a position for attack. There are many examples of vessels that have escaped a submarine by zigzagging. Of fifteen vessels sunk in a certain area, twelve were not zigzagging and two that were trying to zigzag did not understand the proper method of so doing. During the same interval of time in the same area of fifteen vessels that were zigzagging properly one only was lost. In the war instructions two-thirds of the booklet is devoted to the Zigzag course.

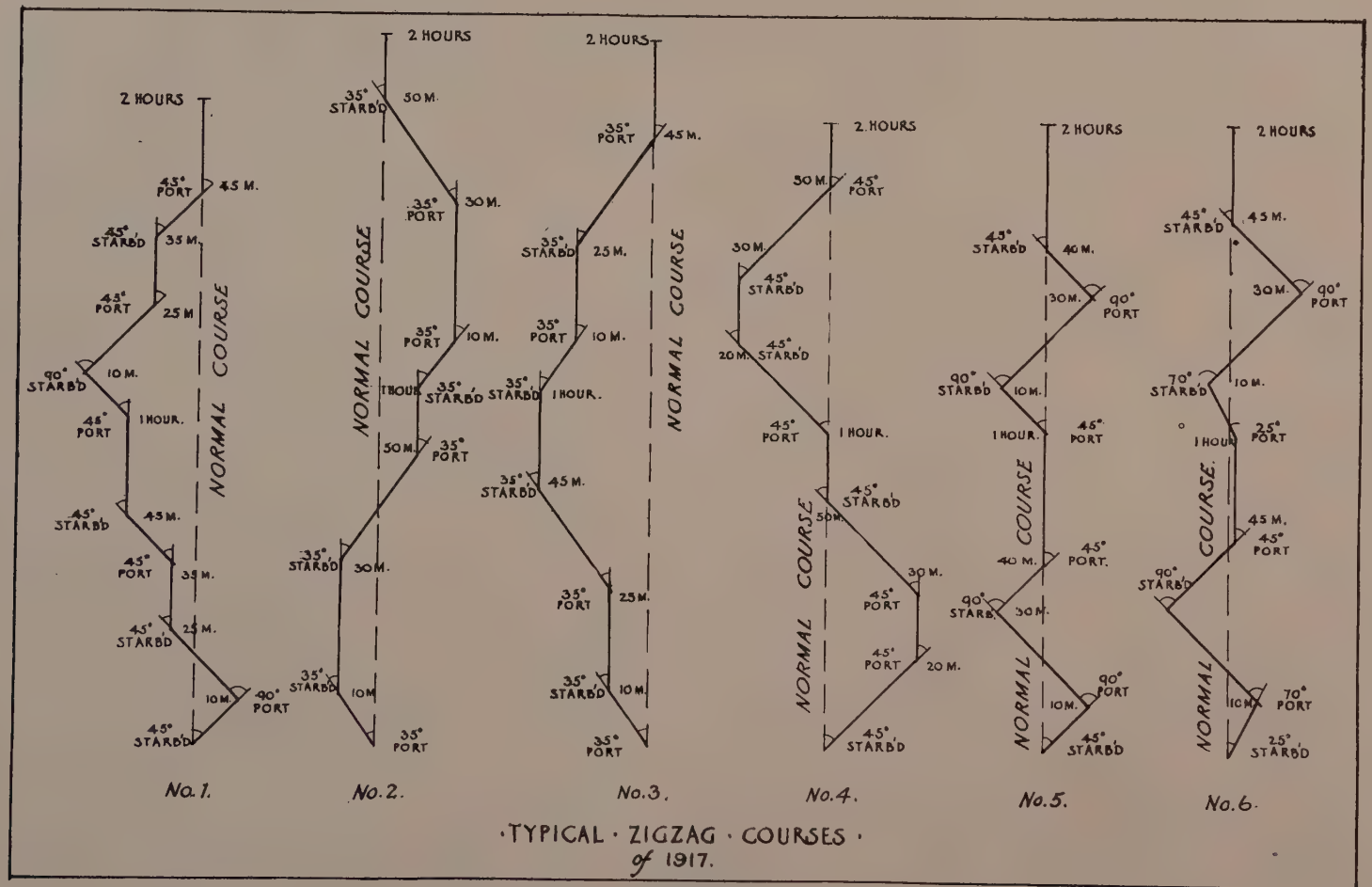


Figure 11
Typical Two Hour Zigzag Courses of 1917

11. THE ZIGZAG COURSE

Prior to the Great War there was no art or science of zigzagging. Up to the time the *Lusitania* was sunk on May 7th, 1915, vessels steered straight courses, with rare changes in direction. In 1915, however, the Zigzag began to be extensively used. The earliest Zigzags had legs from ten to twenty minutes in length and required changes in course of from 25° to 90°. In January 1918 the American Zigzag course was modified by increasing the number of turns from four per hour to six, but the angles of change remained large, save that those over 80° were eliminated. The legs were shortened to some five minutes as a minimum and about seventeen as a maximum. Shortly thereafter further development took place. The freedom of the ship captain to make up his own Zigzags, based upon certain models, was ended and a large list of official Zigzags was issued. There are now single ship Zigzags and convoy Zigzags, Zigzags for slow craft, Zigzags for fast craft. Some are for use in open waters where submarines are rarely met, others for use in the danger-zone in general, and still others for use in hazardous parts of the submarine-infested area. Among those of each category, some are to be used only by ships of over a certain speed and some only by "fast" convoys. Whereas in 1917 the changes in course per hour were only four and in early 1918 at most six, later 1918 courses increased the number to six per hour as a minimum and twelve per hour as a maximum. The angles of change lie between a little less than a compass point and 80°. Some are such irregular figures as 11°, 33°, 34° and 37°. The Zigzag legs now vary from about three minutes and a half to sixteen minutes and a half in duration. One Zigzag course actually carries a 12-knot vessel five miles away from her main course. In several the vessel does not return to her straight course for two or three hours. In some her main course is changed every hour. It is interesting to note the evolution of the Zigzag during the course of the war. Figure 11 illustrates the 1917 and Figure 12 the 1918 types of Zigzags.

There is much to be said in comment upon present and past Zigzag practice. While the manoeuvre adds safety, it does not give immunity from attack. One defect is inherent in all manoeuvres which involve straight line courses, namely, the possibility of a torpedo's or a shell's striking the vessel when still on the leg of the Zigzag. Vessels properly zigzagging have been sunk. The reason is perfectly clear. At a thousand-yard range the torpedo itself is a little less than a minute under way before it reaches the target. The time consumed in the submarine's approach from five thousand yards to the firing-position at one-thousand yard range, is around ten minutes or less. As the present German U-boats are able to travel submerged faster than the older ones, the interval for approach may in the future be taken as even briefer than heretofore. Given these factors, it is manifestly possible for a U-boat to manoeuvre into position and fire during the time a vessel is on many a Zigzag leg. This is especially true when the legs are over ten minutes long, as they are in nearly every case. Zigzagging can be rendered even less of a protection than it is against attack by a single U-boat, if two or more submarines operate to-

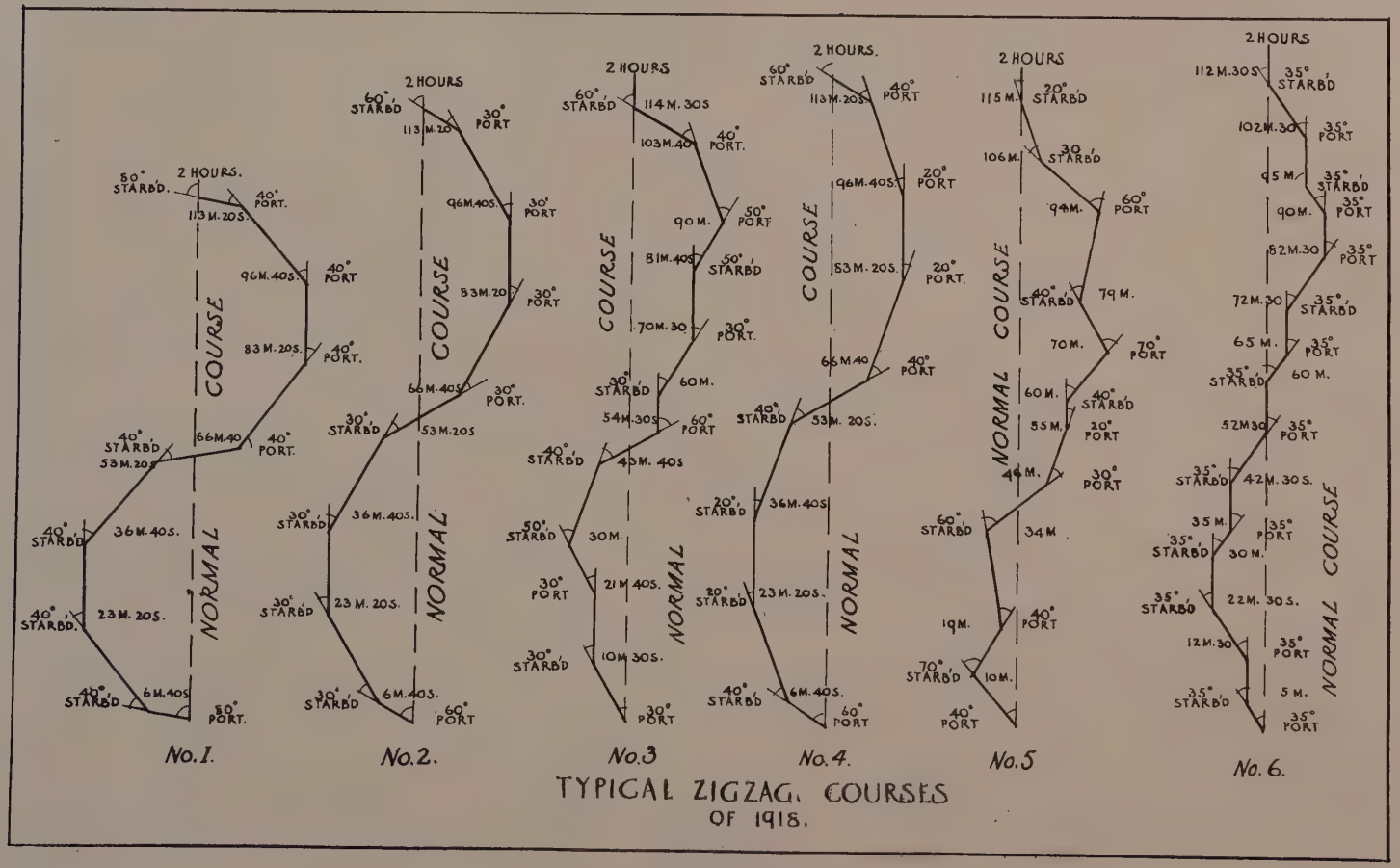


Figure 12
Typical Two Hour Zigzag Courses of 1918

gether. The second submarine has merely to take station well ahead and on the opposite side of the approaching vessel. If a change in Zigzag leg carries the vessel away from the first submarine, she will be placed within the reach of the second. This defect is inherent in straight-leg Zigzag courses where the angle of change is between 25° and 80°.

The Zigzag, furthermore, carries a 10-knot vessel as far off normal sometimes as 6,000 yards. A faster ship is carried even further away. A ship steers through a wide belt while traversing the danger-zone. This may enable a submarine to sight a vessel where otherwise she would slip by undetected, and allows the Germans to cover a given area with fewer U-boats.

The loss in distance traversed on Zigzag, as contrasted with that on a straight course, is calculated as ten per cent for two of the typical courses of 1917, prepared for non-hazardous areas, and as twenty per cent for the four typical Zigzags recommended for dangerous waters. In one of the 1918 courses there is a loss of 31 per cent in distance, and in most a loss of ten to twenty per cent.

The necessity for turning the angles of the Zigzags causes a very material reduction in a ship's speed. According to the official estimates, four 35° changes per hour lessen the speed of an 8-knot boat by 0.8 knots, of a 10-knot boat by 1 knot, of a 12-knot boat by 1.2 knots, and of a 14-knot boat by 1.4 knots. Four changes of 25°, 45°, 70° and 90° respectively, lower the speed of an 8-knot boat 1.6 knots, of a 10-knot boat 2 knots, of a 12-knot boat 2.4 knots, and of a 14-knot boat 2.8 knots. Admiral Austin M. Knight, speaking of 90° changes in course, says:

> "With regard to the speed involved in these curves, this begins to fall off, as might be expected, the moment the helm is put down, the reduction being due to the resistance of the rudder and the sidewise motion of the ship. It continues to fall off until the point is reached where the turning curve becomes uniform and circular, at which point it has fallen off to something like 60 per cent of its original value. From this time on, it remains constant as long as the turn continues with the same helm angle." ("Modern Seamanship," Knight, 1917, p. 308.)

The 1917 Zigzags involved sudden turns through 25° or more in angle of departure. The slowing up due to turning through the given angles was so serious that the legs of the Zigzags could not well be shortened. If the legs were shortened to increase the vessel's safety, her speed was lessened, which diminished her safety. In 1918 vessels when altering course to carry out a Zigzag were advised to use only small helm. This was to reduce the loss of speed in turning and also to make matters more puzzling for the submarine, keeping it longer in doubt as to what the new course was going to be. The loss in speed due to the new Zigzags is not estimated in the instructions but a turn of say 35° made in two, or at most three, minutes, will appreciably retard a vessel. It is doubtful whether the total retardation is less on the 1918 than on the 1917 Zigzags, for the number of turns per hour has been doubled or even trebled, although the time of turning has been lengthened.

One of the serious difficulties encountered in the defense of vessels against attack by submarines is that of insuring correct zigzagging. The reports of the armed guards on merchant vessels indicate that in many instances masters of vessels proceeding alone do not follow the instructions laid down for their guidance. There have been a number of reports of vessels that only began their zigzagging after attack by a submarine. Lieutenant Commander Gill, in an article authorized by the Navy Department, writes:

> "It may be mentioned here that it is extremely hard to control merchantmen and compel them to practice simple anti-submarine tactics—such as steering zigzagging courses, calculated to embarrass the submarine in the accomplishment of its purpose. It is difficult for seamen who for years have navigated the usual lines to understand and carry out instructions intended to safeguard them from a foe they cannot see." ("Anti-Submarine Tactics," Lieutenant Commander C. C. Gill, Current History, October 1917, page 122.)

A large part of the extreme difficulty in enforcing the rules is due to the retardation in speed, loss in distance and to the annoyance and mental labor involved in the Zigzag practice. The slow turns are better than the old sudden turns, which occasioned damages to rudders and gears. Considerable skill is required, however, to make a turn at the required slowness, and to negotiate turns in the fashion now stipulated requires highly trained helm work and constant attention. To attain the designated slowness the number of spokes of the steering wheel to be turned should be computed in advance. While turning, the helmsman has no compass mark on which to rest his eyes, as the last mark has been abandoned and the approaching one is not yet reached. The strain of complexity and the navigation burdens are serious factors to be considered in the practical steering of the later Zigzags. The psychological aversion of ship masters to losing distances has been emphasized by the authorities. This has been increased rather than diminished by the final Zigzags.

Professor W. MacNeile Dixon, of the University of Glasgow, summarizes the limitations of the Zigzag course in the following words:

> "Zigzagging, however, adds materially to the length of the voyage and the time consumed by it is cordially disliked by skippers. A temptation naturally assails men of their breed to make a dash for it. Time, too, is always a consideration, and the risks to a vessel of less than 10 knots speed are not appreciably diminished by its adoption. For an 8-knot boat, and many of the most valuable traders can hardly attain a greater pace, the increase in the length of the voyage and the time involved balance or eliminate the advantage of this and other palliatives." ("The Fleets Behind the Fleet," Prof. W. MacN. Dixon, 1917, page 49.)

12. THE SINUOUS SPIRAL COURSE

Inasmuch as at present the Zigzag is held to be, with armament, a ship's chief self-defense reliance, and as it is a feature of some anti-submarine battle-manoeuvres and all anti-submarine precautionary-manoeuvres, it is important

to improve the system to the fullest possible extent. It is highly desirable that a manoeuver be devised which will ensure greater safety, speed, and distance made good, and which may be executed with ease. Logically, it would appear that the best manoeuver for causing confusion in the calculation by a U-boat of a ship's course, speed, and range would be for the latter never to be going in a fixed direction, at a constant speed, or to be seen at the same view. A track consisting of a series of irregular spiral curves, called a "Sinuous" or an "S" course, to contrast it with a Zigzag course, has been proposed by the writer as a perfected feature of a precautionary and battle-manoeuver. The best course, that is, the type permitting the greatest speed and distance with the most immunity from torpedo or gunfire hits, is a succession of simple or compound graduated spiral arcs, such that the curves will melt into one another. Portions of spirals should be selected of sufficient curvature to cause observation confusion, yet such as will not over retard a vessel nor lose her too much distance as compared with a straight course.

The proposed "S" course should not be confused with the path of a vessel caused to weave like a fish through the water, by alternately putting the helm over to starboard and to port. The so-called weaving has practically no effect upon the accuracy of torpedo fire, since it causes no material change in the vessel's course, and only serves to cut down her speed. A suitable "S" course, on the other hand, produces a decided change in the vessel's position and carries her to a place other than that at which a submarine would expect to find her after a given interval.

The embarrassment of a submarine captain when attempting to determine the course, speed and range of a vessel steaming on a curve is manifest. It is sufficiently difficult to gauge accurately the direction of a vessel proceeding in a straight line. From a distant U-boat, the angle of departure of a curved course is well-nigh impossible of determination. A continuous, progressive and irregular variation in the angle of departure will complete the observer's confusion. Calculation of the speed also of a vessel on a curved course will be more difficult than it is now, because the time taken by the ship to traverse the space between two points separated a known distance will vary according to the curve followed. If the cross-hair image-measurement method is employed by the observer to determine the range of the target vessel, the range-estimate also will be adversely affected in the case of a ship proceeding on a curved course, because the perspective view of the vessel, measured between the cross-hairs, will be constantly changing.

If the submarine captain takes frequent observations and notes that his first estimates of speed, course and range are inexact, he may be expected to pause and put up his periscope for a long observation. The very fact that the submarine's invisibility has been jeopardized and that the initiative has been taken away from it, is a big advantage for the surface vessel. If the submarine captain does not take several observations, but submerges and rises where the first observations indicate the firing-position will be, he will rise only

to find himself out-manoeuvered. If the curved course has carried a vessel away from the point at which the submarine expected her to be, the U-boat will find itself at a greater range than was expected and with angle greater or less than between 70° and 90°, which is a decided handicap. If the curve has carried the vessel toward the submarine, the range is shortened, but the angle has been made acute. In this case, also, the opportunity may be presented to the vessel to over-run the submarine. There is also a chance of the curve's changing to the other direction before a torpedo hits, inasmuch as the curves of the proposed "S" courses change at short intervals. If the curve has carried the vessel away from the submarine, a change of curve in a direction toward the U-boat will not be necessarily a serious matter, since the curves are gradual.

As the course, range and speed-estimate of the U-boat commander will be inaccurate, he will be unable to determine by triangulations the location of the torpedo firing-position. Should he endeavor to use the "Rule of Thumb," proceeding towards the ship's course on a line perpendicular to the line of bearings, difficulties will also be experienced. As the ship's speed is not precisely known, he will be uncertain what submerged speed to use. Full speed may carry him far in the wrong direction, slow or moderate speed may lose him the chance to attack. As the vessel's course is constantly changing, he may be frequently at a loss to know which way along the perpendicular will be the way towards the ship's track. Inasmuch as the successive lines of bearing will never be parallel, the U-boat will have to materially change course after every observation. This involves delay, confusion and uncertainty. In order to obey with any degree of accuracy the "Rule of Thumb," the number and duration of periscopic views will have to be increased, thereby exposing the U-boat to discovery. Even should the submarine happen to come within the desired range, the chances will be slight that the line of bearing's angle γ will also be around 90°, yet close range and beam position are both of vital moment to the success of torpedo attack.

If a surface vessel is attacked by two or more submarines, the U-boats' position-manoeuvres will be seriously disturbed by irregular curves steered by the target-vessel. Inasmuch as submerged submarines are invisible to each other and underwater signalling during an attack is practically impossible, the uncertainty of the submarines' captains as to where to take station and the fear of one U-boat's colliding with the other or of being hit by a stray torpedo are all advantages for the prospective victim.

An adequate idea of the speed retardation which is incident to steering a curved course may be obtained from data appearing on a chart of the torpedo danger-area prepared by Commander Knapp and Lieutenant Commander Logan. The chart shows the loss in advance in a five-minute period of a 12-knot vessel under full speed when the helm is put over through various numbers of compass points a half minute after beginning the timing. ("Useful Curves, Scouting, and the Torpedo Danger Area," Com. H. S. Knapp and Lt. Com. G.

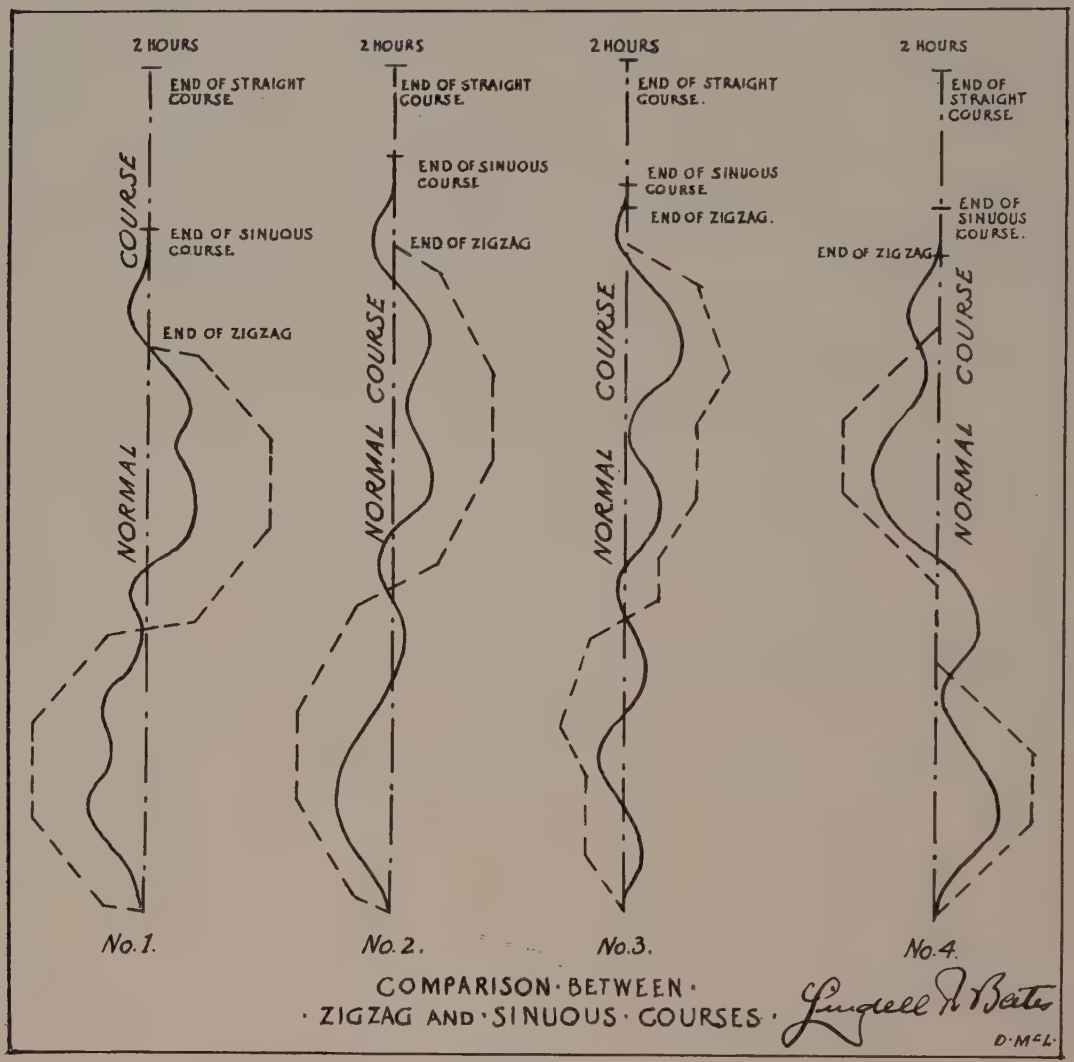


Figure 13
Typical "S" Courses Contrasted with Straight and Zigzag Courses

W. Logan, 1908, plate 1.) A table prepared for the writer to illustrate approximately the loss in advance due to steaming on various curves is as follows:

	Yards Advance	Yards Loss in Advance	Yards Transfer
Straight Course	2,000	..	..
Angle of Departure 1 pt. (11¼°)	1,960	40	312
Angle of Departure 2 pts. (22½°)	1,856	144	560
Angle of Departure 3 pts. (33¾°)	1,704	296	784
Angle of Departure 4 pts. (45°)	1,528	472	960
Angle of Departure 5 pts. (56¼°)	1,352	648	1,088
Angle of Departure 6 pts. (67½°)	1,144	856	1,168
Angle of Departure 7 pts. (78¾°)	984	1,016	1,200
Angle of Departure 8 pts. (90°)	792	1,208	1,176
Angle of Departure 16 pts. (180°)	200	1,800	539

It may be readily seen how slight is the loss in advance due to steaming upon a curve of long radius and a small angle of departure. In locating railroads it has been found that a curve in a roadbed with the course laid out on spiral arcs permits greater train-speed to be made than a curve which is an arc of a circle.

13. ADVANTAGES OF THE "S" COURSE OVER THE ZIGZAG

Since the suggestion that the Zigzag be replaced by the "S" course is a novel one, the relative advantages and limitations of the two methods must receive careful attention. Figure 13 shows a typical series of "S" courses contrasted with the Zigzags.

In respect to safety, it is clear that a vessel proceeding on a graduated spiral curve is more immune from torpedo attack than a vessel on a series of straight legs, even when connected by curved corners. Should the U-boat reach a firing-position while the vessel is on a Zigzag leg there is opportunity for the torpedo to reach her before the time for her next course change. A U-boat commander may sometimes guess the amount of the next Zigzag turn. This is especially true in the case of several of the 1917 and 1918 Zigzags, since the same angle is used for each change.

There is considerably less retardation on the "S" curves than on the official Zigzags, inasmuch as in the former the curve is gradual, though sufficient to confuse a submarine's observer, whereas in the latter there are several changes in course through large angles of departure. To steer a straight course, the helm has to be put frequently slightly to port and to starboard in order to keep the line. In steering a curve, the helm has to be put over for a longer period to port and shorter to starboard, or vice versa. If the curve is gradual the resistance of the ship to the passing water in the two cases does not differ greatly. It is to be anticipated that eight or more turns an hour through from 25° to 70°, in from two to three minutes each, will cause more retardation than a continu-

ous change of from 3° to 6° a minute. An "S" course causes no material loss in speed while a Zigzag, even with rounded corners, is bound to cause some appreciable retardation.

The distance to each side of the vessel's normal course may be with proper safety, less on a suitable "S" course than on the Zigzags. There is, therefore, a better chance for a vessel on the improved curved course manoeuvre to get through the danger-zone unobserved.

On a scientific "S" course, the distance advanced toward port is greater than on a Zigzag. The respective losses in distance due to steering a Zigzag and an "S" course in comparison with the straight course and with each other may be seen from Figure 13. In the case of the "S" courses prepared for dangerous waters, there is a gain of 8% to 12% in the two-hour stretch over the corresponding Zigzags.

The "S" course is also of value to the defense of merchantmen against attack by gunfire from a U-boat. The instructions now require a vessel to zigzag away from the submarine. But the straight legs of a Zigzag render her vulnerable a large part of the course, whereas spotfiring against a vessel on a sinuous course would be most difficult. This is especially true from a low-lying submarine from which as a base gradual changes in course angle are next to impossible to determine. It takes a pronounced turn to be readily and speedily noted by the submarine's observer. It would take the submarine's gun crew several more minutes than now to get the mean point of impact and then the point could not be held owing to the ever-varying curves of the target's course. Escape from submerged pursuit is also facilitated by steering a curved course, as a submarine captain is only able to guess where to proceed to cut a vessel off.

It will be noted with interest that the Zigzags of 1918, illustrated in Figure 12, were prepared after the writer's confidential booklet on this same subject had appeared in November, 1917, and had been called to official attention. Some of the later Zigzags approach as near "S" courses as Zigzags can. But a series of Zigzags cannot be devised which will attain the protective qualities of the graduated spiral "S" course. The "S" course is the ultimate scientific refinement of the Zigzag as a precautionary manoeuvre against torpedo attack. Not alone does it add to safety, but, by cutting the Zigzag corners, a greater distance toward port is made good, the distance away from normal is reduced, and ship's speed is greater.

Mr. Laurence Y. Spear, President of the Electric Boat Company and one of America's leading torpedo experts, gave his opinion before the District Court in the *Lusitania* case, in June, 1918, relative to the "precautions that a steamer can take against successful submarine attack." His valuable opinion states:

> "No. 1 is to keep the best possible lookout, because the early sighting of the submarine may in some instances enable you to escape. No. 2 is to steer such a coursse as will be most difficult for the submarine command-

er to anticipate where you are going to be next; in other words, an irregular curved course, with the ship always under rudder, so that at no time, except for some very short interval of time, is she pursuing a straight course; that would, in my judgment, be the most effective way to make it difficult for the submarine to carry out the first part of the attack—generally termed the approach—that is, to get within proper distance. Of course, any such course might lead you within torpedo distance, when a straight course would not; but speaking broadly, taking the chances all together, I think that a continuously varying course would probably be the most effective means you could adopt."

14. ZIGZAG CHARTS, CLOCKS AND SIGNAL BOARDS

In order to facilitate zigzagging, the naval authorities first suggested that a cardboard disc be placed around a clock face and that the disc be marked on the inner ring in black for alterations in course in the first and odd numbered hours and in red for the second and even hours. Figure 14

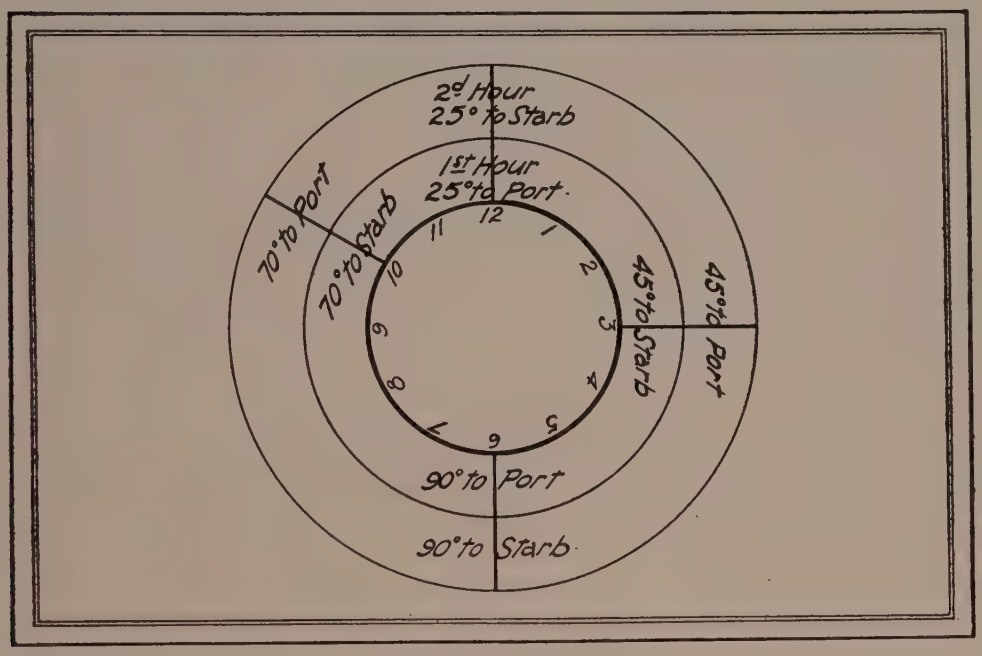


Figure 14
The Disk Course Indicator Board

illustrates the suggested disc as applied to a typical Zigzag. An improvement in this device was made by an officer of a British merchant vessel, the patent of which was purchased by Captain Arthur W. McGray, now employed by the Emergency Fleet Corporation. The indicator is illustrated in Figure 15. Describing this signal board, Scientific American says:

"It consists of a board about two or three feet square, carrying in its center a clock, and on each side of the clock a series of alternate green and red cards and glow lamps, each card and lamp corresponding to the starboard and port courses on which the ship is being navigated, at any given time. Above the clock, extending across the head of the board, is plotted a Zigzag course which it will take the ship one hour to cover." ("Submarine Problem VII, the Zigzag Course as a Defense against Submarines," The Scientific American, July 14, 1917, page 31.)

When the bell rings for a change of course, the Navigation Officer on the bridge pulls out a plug in a circular ring surrounding the clock and moves it to the next hole corresponding to the next change of course. The bell continues ringing until each change has been made. The British have developed an Admiralty clock which rings a bell at the time for Zigzag turns but which has not the chart of the McGray Indicator.

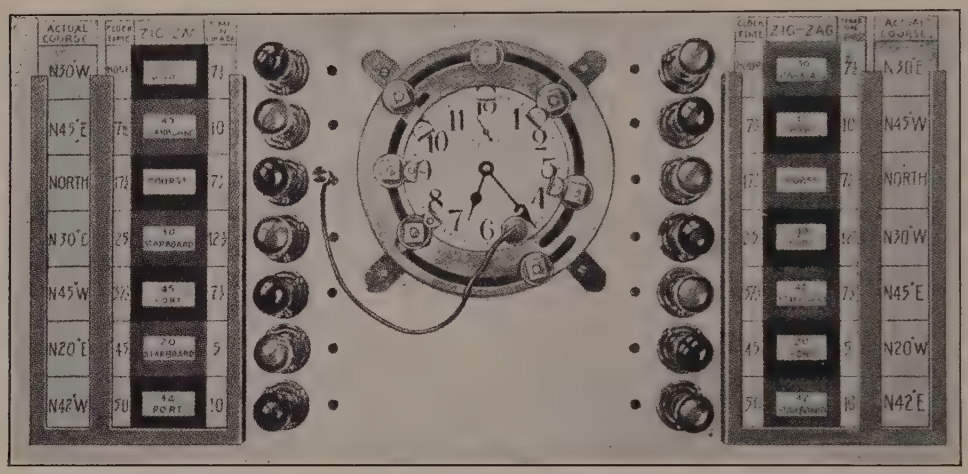


Figure 15
The Clock Course Signal Board

The cardboard disk has to be especially prepared for each course and constant attention must be paid by the helmsman in order to not miss a change of course. The clock device is an improvement, but is subject to the same serious objection. Both boards divert the attention of the helmsman from his compass when steering, require a change in compass-mark observed, call for close attention, before, during and after using them, and place a severe burden upon both the helmsman and Navigation Officer. These measures were unusual to many of the less experienced ship masters and especially to helmsmen accustomed to a fixed routine.

Some American vessels now carry the course signal board or clocks without the board. British vessels carry the Admiralty course signal clock. Other ships employ the old cardboard disc and many use only a chart. All are put to considerable trouble and a considerable number of those not in convoy still evade the duty and steer a straight course.

While the advantages of the "S" course as a protective manoeuver are not and cannot be seriously challenged, the natural question arises how are vessels to steer such courses. It is indeed true that if the compass is disregarded, a vessel can be steered in an arc of circle, of curvature determined by her helm angle and turning qualities, but if the helmsman attempts to combine even these arcs he will soon be navigating at random and without an idea of his geographical position at sea. For him to return to a fixed course and position at a given future time is quite out of the question. To steer a curved course with present practice, it is necessary to steer chords of the arc by changing compass-marks at stated intervals. This is the arduous method now utilized to steer scouting "search curves." But the chord system cannot be used when the curved course has changes in angle of departure of say 3.5°, 6°, 8.5°, and 5° on successive minutes or fractions thereof. To perform even a simple "search curve" spiral the navigating officers must undertake laborious calculations to ascertain the requisite compass-mark changes and the time schedule. To change compass-mark an irregular number of degrees in an irregular and brief time interval is now an impossible navigation feat. To ask merchant ship helmsmen and officers to do so is out of the question.

None of the course signal boards, discs or clocks facilitate steering curved courses, as the chief obstacle is the very necessity of constantly selecting a new compass-mark to steer by. Bells cannot be ringing or lights flashing at every moment for a change in course. To steer an "S" course, and even to steer well a Zigzag, means must be found to improve the navigation methods now in vogue.

15. THE AUTOMATIC COURSE INDICATOR

Having regard to the foregoing considerations, the writer has invented an automatic course indicator. It has been prepared with the following ends in view:

1. To enable a ship to steer Zigzags, scientific "S" courses, spiral curves, or combinations of them, with precision.
2. To impose upon the helmsman in such navigation no duty in addition to the one to which time and experience have accustomed him—namely, that of watching the compass and maintaining in alignment on it the normal compass-mark with a lubber line.
3. To supply the Navigation Officer and helmsman at all times with definite information, in intervals of time and units of distance, relative to the position of the vessel on the Zigzag, "S" course, or curve, and relative to the normal straight course.
4. To provide an instrument suited to any vessel, whatever her speed, and whatever her variations in speed, her size and other characteristics, and adaptable to any type of compass, magnetic or gyroscopic.

Ships are now navigated by using the helm in such a fashion that a lubber-line on the compass rim, set in line with the vessel's longitudinal axis, is kept opposite a selected compass-mark on the compass card. If, for example, a vessel proceeding North is desired to go East, the helmsman turns the ship until the East mark of the compass is opposite the lubber-line. If, however,

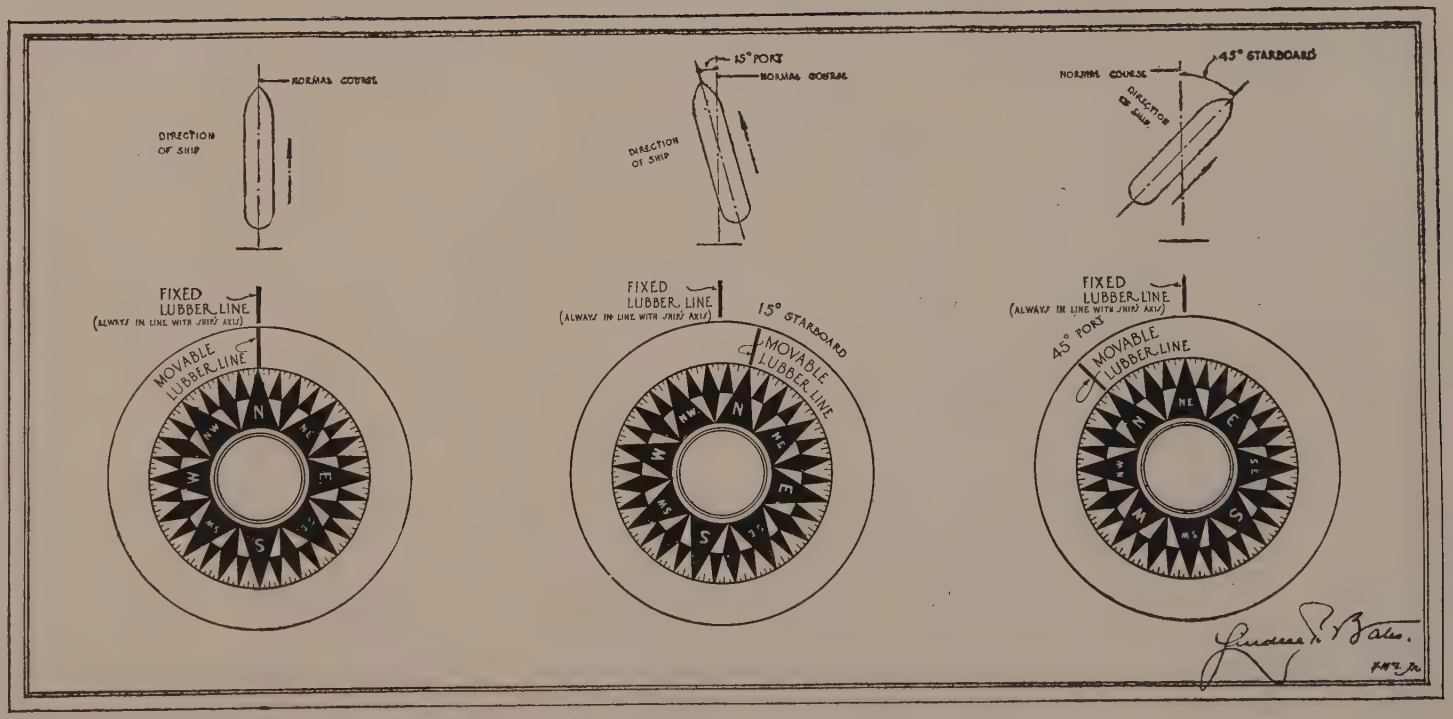


Figure 16
The Principle of Navigation with a Movable Lubber Line

the lubber-line were not set in line with the ship's axis, but were positioned on the compass rim, let us say, 15° to the right or starboard of the axis line, then the vessel would not be steering North but 15° to the West of North. Figure 16 shows this principle. Should the lubber-line be moved to the left or port of the usual axial position, and should the vessel then be turned so that a given compass-mark is in alignment with the lubber-line, the ship will be found to be heading East of that compass direction, the same number of degrees as the line was moved to the left of its axis line position. Any predetermined course may, therefore, be translated into terms of lubber-line movement. Hence, given any compass-mark, a vessel may steer, with that direction as a base line, any desired curve. She may turn completely around, always keeping the same compass-mark opposite the same lubber-line.

The mechanical principle of the Automatic Course Indicator is, therefore, simply this: A movable lubber-line is rotated about the compass card according to a predetermined course. If the line moves to the left or right of a fixed lubber-line, then by causing the selected compass-mark to follow it the vessel will go to starboard or port respectively. The helmsman today is accustomed to look at a given course-mark on the compass and to keep opposite it a fixed lubber-line. With the Automatic Course Indicator, the helmsman keeps the same normal course compass-mark opposite a movable lubber-line instead of a fixed one. When he wishes to discontinue the precautionary, battle, or scouting manoeuvers, and return to his normal straight course, he looks at an emergency fixed lubber-line and places it opposite the same normal course compass-mark. Thereafter he sets the movable lubber-line back in its axial position and uses the compass in the old way. The principles and apparatus are recognized as so revolutionary and new in navigation that basic letters patent have been granted upon all claims.

There are any number of ways for rotating a lubber-line around the compass card. In the case of the gyroscopic repeater compass an arrow would be rotated around the stationary compass bowl. This may also be done with the magnetic or the whole compass bowl already carrying its lubber-line may be rotated. As the device was primarily intended to meet the U-boat menace and as merchant vessels are all equipped with the magnetic compass, Model No. 1 of this instrument was made for use with this type of compass.

The Automatic Course Indicator, Model No. 1, is shown in Figure 17. It may be described as follows: The outer shell of the magnetic compass carries the usual lubber-line, but the shell is capable of being automatically rotated, so that the line is moved from the normal position to port and to starboard. A lock at the left side of the Binnacle Case connects or disconnects the automatic mechanism. The magnetic feature of the compass is not disturbed or modified. The outer gimbals of the compass are carried by two brackets fastened to and rising from a rotatable table. The table or compass-support is carried on the upper end of a taper spindle supported in ball-bearings in a frame rigid with the Binnacle Case. The table is fixed when the compass is used as an ordinary compass, and is rotatable when the automatic mechanism is employed. The auto-

Figure 17
Photograph of the Automatic Course Indicator, Model No. 1

matic mechanism consists of a grooved cam held to the face of a disc. The groove of the cam is engaged by freely rotating roller held near the end of a lever, which actuates a rack and pinion, so that when the lever is swung in either direction from its initial true position by movement of the roller in the groove of the cam, a corresponding, but greatly increased, movement is imparted to the compass supporting table. The movement of the lever is converted, however, into a rotary movement of the table. A rod extends vertically down through the base of the Binnacle Case to a small electric motor, placed at a distance from the magnetic compass so that the latter will be unaffected. This motor receives current from a turbo generator. Rheostats and a clock synchronizer of a special type ensure the desired speed rotation of the cam and prevent cumulation of time advance or delay. The self-regulating speed con-

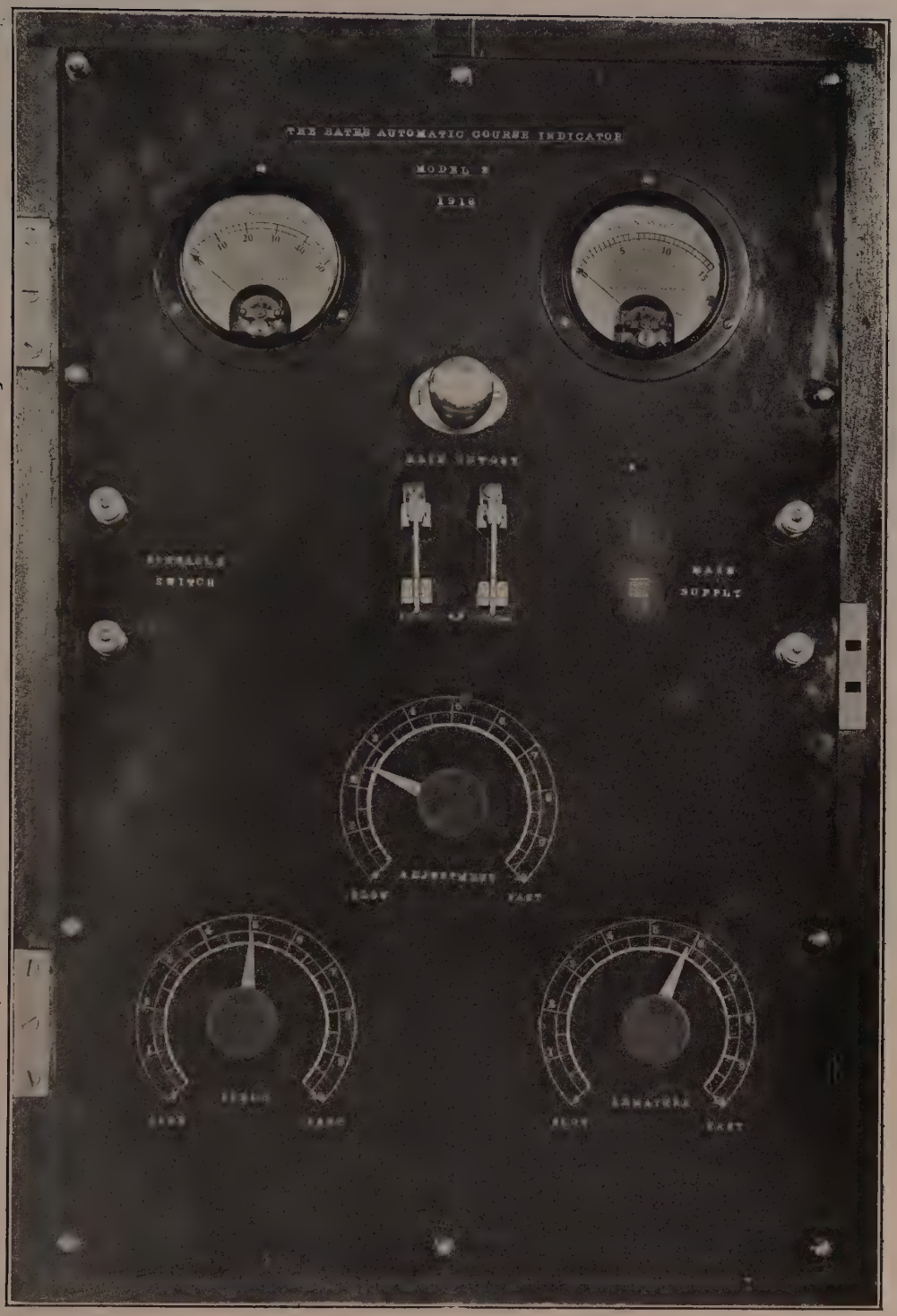


Figure 18
Motor Speed Adjustment Panel of Model No. 2 of the Automatic Course Indicator

trol panel of Model No. 2 is shown in Figure 18. Special attention is focused on time accuracy, as this is a vital factor when dead reckoning at sea is involved and fleet or convoy manoeuvers are undertaken with the aid of the instrument. A thumb button turn-switch is provided on the side of the Binnacle Case with which to start and stop the mechanism. The ship's course to be steered is routed on a cam. Three cams are shown in Figure 19. They are "S" Courses Nos. 1 and 3 and Zigzag No. 5 of 1917. The cams are of aluminum and are divided into 60 minute intervals by radial lines. The "S" course or Zigzag groove is plotted on either side of a normal line which represents the lubber-line in line with the axis of the vessel. As the Zigzags are two hour courses while the cams for Model No. 1 are one hour cams, a special trip is provided to guide the roller into the proper grooves. The axis of the vessel at each minute, with reference to normal course, is shown on the Course Map corresponding to the cam used, as in Figure 20. Tables of Distances, shown in Figure 21, corresponding to the "S" courses, are also furnished. If it is desired to know where a vessel is located with respect to normal course or starting point, look to the table corresponding to the cam used, turn to the column corresponding to the speed the vessel has been actually making according to her log record or Sanborn Indicator record. Opposite the minute since starting the cam will be noted the distance of the vessel along the "S" course, along the normal, and away from the normal. For dead reckoning purposes the tables are of great value and adequate accuracy.

If it is desired to allow for compass variation, without changing compass-mark, an adjustable plate on the lever arm may be utilized to compensate therefor by starting the lubber-line to the right or left of the axis line position. If it is desired to allow for compass deviation, the same method may be followed. In this case, however, the deviation selected may be that of the normal course or the average of the port and starboard deviations of the "S" or Zigzag course selected. Inasmuch as the time to port and to starboard on an "S" course is in nearly every case about equal, either system may be used, and a Table of Deviation Compensations may be prepared in view of the deviation table of the compass. It is possible to provide for the exact deviation by allowing for this factor in designing the groove upon the cam, but for all practical purposes the above indicated allowances are sufficient. If it is desired to allow for current, tide, or wind, the same method may be utilized.

The same mechanism may be used with the gyroscopic repeater compass, with slight modifications. The rotating table upon which the magnetic compass is mounted would be replaced by a gear meshing with another gear carrying an indicator arrow, which latter gear would rotate around the repeater compass. As the gyroscopic compass is unaffected by the presence of iron and steel, the motor and clock synchronizer may be placed close to the cam disc and speed gears. A compact and neat apparatus for use on naval vessels is readily available.

Model No. 1 of the Indicator was installed upon the U. S. S. ——, a vessel assigned by the Navy Department to the Submarine Defense Association for

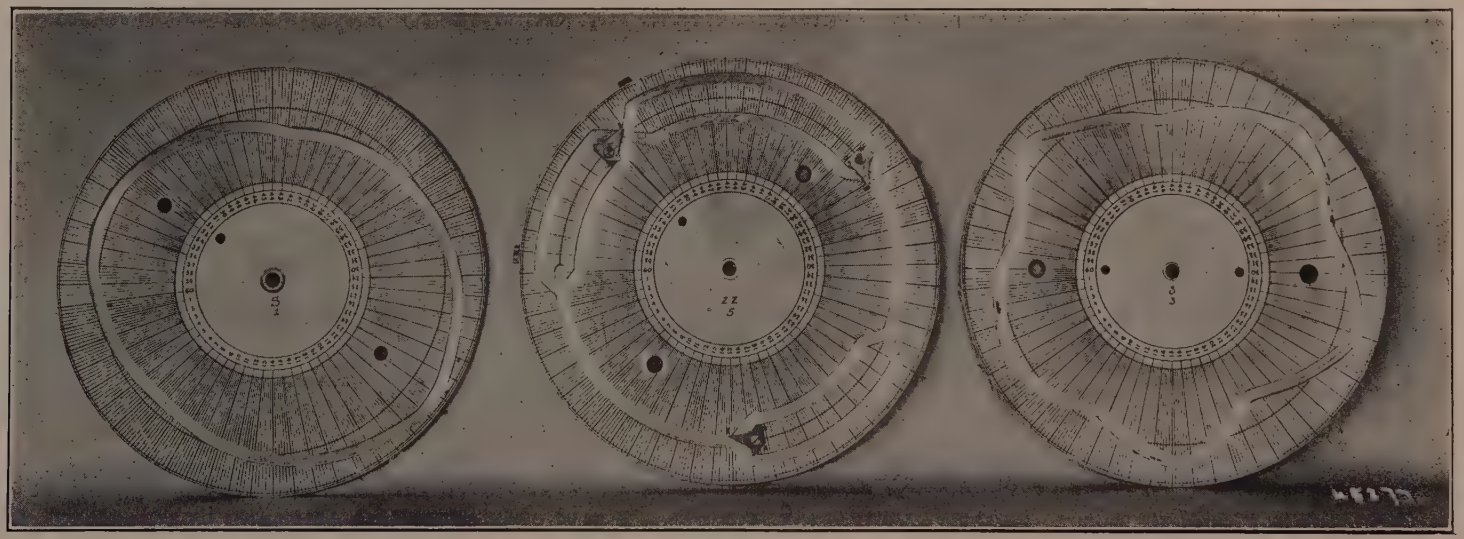


Figure 19
Cams for Courses S1, S3 and Zigzag No. 5 of 1917

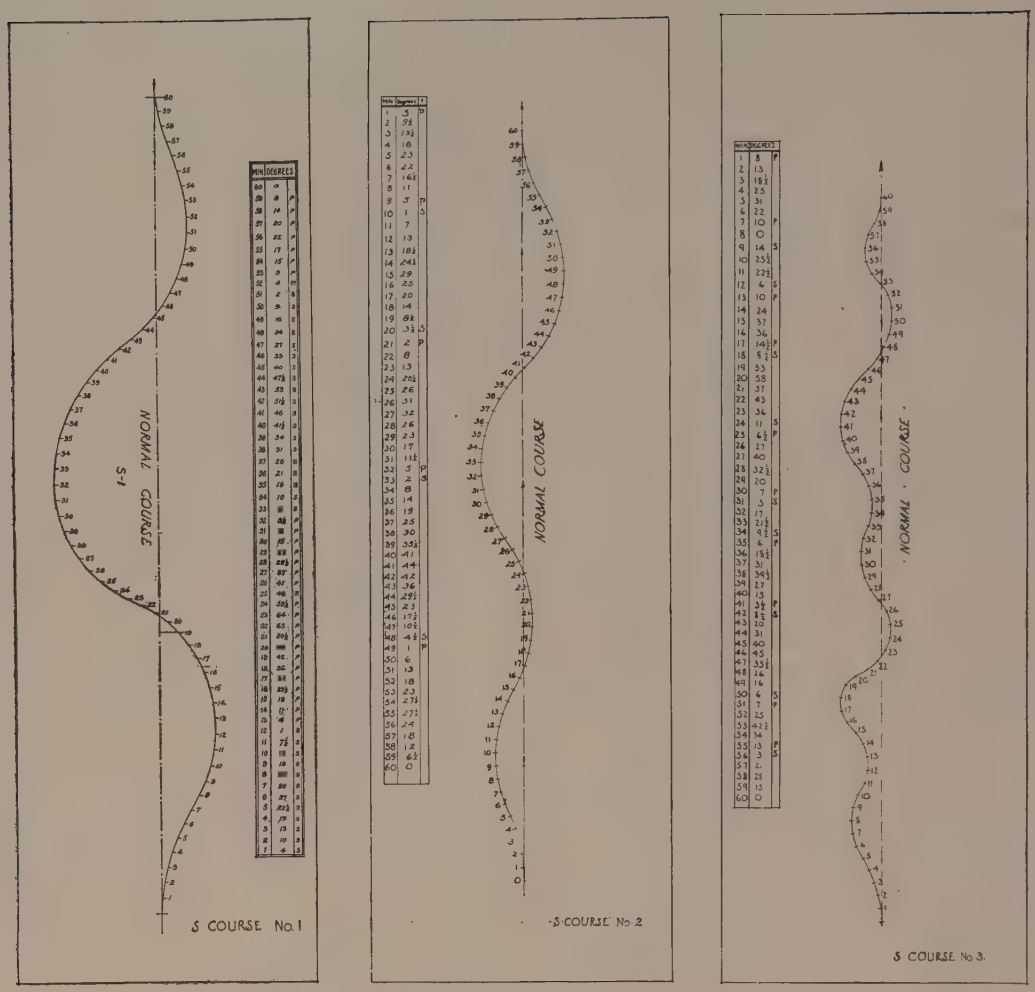
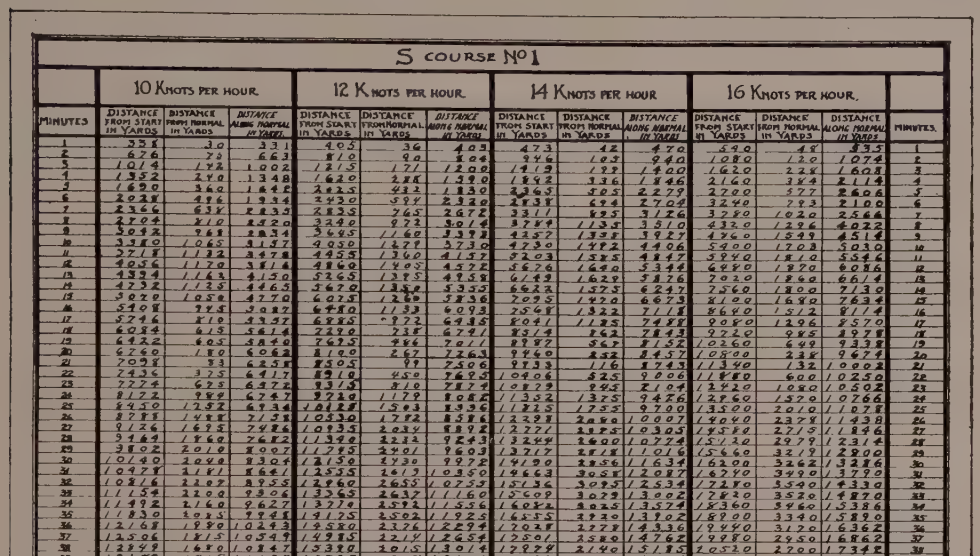


Figure 20
One Hour Sinuous Courses S1, S2, and S3, with Table of Angles

research and demonstration purposes. For six months in 1918 the apparatus was tested under varying conditions in Long Island Sound and in the seas adjacent to the coast. The ship in all her navigation possessed no other compass and her table of deviation showed even less deviation than the table corresponding to her old compass. The experience with zigzagging in the war has been so extensive that no one has or will question the value of "S" courses as a defense against submarine attack. Ability to steer such curved courses is the vital question. Without entering into the details of the tests made, it is in order to state briefly certain of the salient facts, witnessed by over a hundred experts in naval and merchant-ship matters. A movable lubber-line may be followed with the compass card, even in a heavy sea. The lubber-line movement is very slow as the curves are gradual. Even a sluggish vessel will be able to respond to the helm in sufficient time to navigate the desired curve. The new

electric steering device on battleships will harmonize perfectly with the indicator, for with the ordinary helm accurate curved course steering has been readily accomplished. A vessel will come close to her desired position upon completion of the cam course. On one typical occasion, for example, the U. S. S. ——, navigating in a heavy fog, steered one hour to sea and one hour back, on different "S" courses, and she returned to within one hundred yards of her start-



S COURSE NO 1

MINUTES	10 KNOTS PER HOUR.			12 KNOTS PER HOUR.			14 KNOTS PER HOUR			16 KNOTS PER HOUR.			MINUTES
	DISTANCE FROM START IN YARDS	DISTANCE FROM NORMAL IN YARDS	DISTANCE ALONG NORMAL IN YARDS	DISTANCE FROM START IN YARDS	DISTANCE FROM NORMAL IN YARDS	DISTANCE ALONG NORMAL IN YARDS	DISTANCE FROM START IN YARDS	DISTANCE FROM NORMAL IN YARDS	DISTANCE ALONG NORMAL IN YARDS	DISTANCE FROM START IN YARDS	DISTANCE FROM NORMAL IN YARDS	DISTANCE ALONG NORMAL IN YARDS	
1	338	30	331	405	36	403	473	42	470	540	48	535	1
2	676	79	663	810	90	804	946	103	940	1080	120	1074	2
3	1014	172	1002	1215	171	1200	1419	199	1400	1620	228	1608	3
4	1352	290	1348	1620	288	1590	1892	336	1846	2160	384	2114	4
5	1690	360	1645	2025	432	1830	2365	405	2279	2700	477	2606	5
6	2028	496	1934	2430	594	2320	2838	694	2704	3240	783	2100	6
7	2366	634	2235	2835	765	2672	3311	895	3126	3780	1020	2566	7
8	2704	810	2520	3240	972	3014	3784	1135	3510	4320	1296	4022	8
9	3042	968	2834	3645	1160	3392	4257	1392	3987	4760	1549	4518	9
10	3380	1065	3137	4050	1429	3730	4730	1792	4406	5400	1703	5030	10
11	3718	1132	3478	4455	1360	4157	5203	1585	4847	5940	1810	5546	11
12	4056	1170	3814	4860	1498	4572	5676	1680	5344	6480	1870	6086	12
13	4394	1163	4150	5265	1398	4958	6149	1629	5876	7020	1860	6614	13
14	4732	1138	4465	5670	1356	5335	6622	1575	6247	7560	1800	7130	14
15	5070	1058	4770	6075	1236	5736	7095	1420	6673	8100	1680	7634	15
16	5408	795	5087	6480	1133	6093	7568	1322	7118	8640	1512	8114	16
17	5746	810	5437	6885	972	6485	8041	1125	7588	9080	1296	8570	17
18	6084	613	5814	7290	738	6741	8514	862	7843	9720	985	8978	18
19	6422	605	6140	7695	756	7011	8987	882	8152	10260	648	9338	19
20	6760	180	6062	8100	267	7263	9460	252	8457	10800	238	9671	20
21	7098	33	6258	8505	99	7506	9933	116	8743	11340	132	10002	21
22	7436	375	6917	8910	450	7695	10406	525	9006	11880	600	10250	22
23	7774	625	6772	9315	810	7874	10879	945	9104	12420	1080	10502	23
24	8112	794	6747	9720	1179	8085	11352	1375	9426	12960	1570	10766	24
25	8450	1252	6934	10125	1593	8396	11825	1733	9700	13500	2010	11078	25
26	8788	1488	7158	10530	1772	8586	12298	2080	10007	14040	2378	11438	26
27	9126	1675	7486	10935	2034	8898	12771	2425	10303	14580	2715	11846	27
28	9464	1760	7682	11340	2212	9243	13244	2600	10724	15120	2979	12314	28
29	9802	2010	8007	11745	2401	9603	13717	2818	11016	15660	3219	12900	29
30	10140	2040	8304	12150	2430	9972	14190	2856	11634	16200	3262	13286	30
31	10478	2181	8641	12555	2613	10350	14663	3058	12087	16740	3490	13770	31
32	10816	2207	8955	12960	2655	10755	15136	3095	12534	17280	3540	14330	32
33	11154	2200	9306	13365	2637	11160	15609	3078	13002	17820	3520	14870	33
34	11492	2160	9627	13770	2592	11556	16082	3024	13574	18360	3460	15386	34
35	11830	2093	9948	14175	2502	11925	16555	2930	13902	18900	3340	15890	35
36	12168	1980	10242	14580	2376	12294	17028	2773	14336	19440	3120	16362	36
37	12506	1815	10549	14985	2214	12654	17501	2583	14762	19980	2900	16862	37
38	12949	1630	10847	15390	2015	13014	17974	2340	15185	20520	2700	17342	38
39	13182	1515	11132	15795	1818	13208	18447	2120	15706	21060	2421	17810	39
40	13520	1312	11417	16200	1525	13698	18920	1848	15993	21600	2100	18254	40
41	13858	1050	11669	16605	1224	14058	19393	1523	16347	22140	1725	18674	41
42	14196	825	11924	17010	920	14319	19866	1127	16705	22680	1320	19082	42
43	14534	571	12128	17415	684	14571	20339	800	16989	23220	913	19018	43
44	14872	315	12346	17820	378	14823	20812	441	17283	23760	504	19754	44
45	15210	75	12527	18225	90	15102	21285	126	17609	24300	120	20126	45
46	15547	120	12845	18630	149	15399	21758	168	17955	24840	192	20528	46
47	15886	278	13107	19035	332	15741	22231	389	18354	25380	444	20978	47
48	16224	420	13412	19440	504	16110	22704	588	18785	25920	673	21470	48
49	16562	525	13729	19845	630	16479	23177	735	19215	26460	840	21962	49
50	16900	601	14092	20250	721	16857	23650	840	19696	27000	960	22466	50
51	17238	638	14357	20655	765	17262	24123	893	20129	27540	1020	23006	51
52	17576	659	14718	21060	783	17667	24596	915	20331	28080	1092	23546	52
53	17914	623	15086	21465	747	18072	25069	833	21000	28620	996	24086	53
54	18252	563	15392	21870	675	18459	25542	723	21585	29160	900	24602	54
55	18590	466	15694	22275	558	18837	26015	570	21966	29700	745	25108	55
56	18928	345	16001	22680	414	19206	26488	421	22407	30240	552	25600	56
57	19266	240	16307	23085	288	19584	26961	304	22838	30780	384	26102	57
58	19604	128	16695	23490	153	19989	27434	172	23310	31320	204	26632	58
59	19942	60	17014	23895	72	20394	27907	96	23783	31860	96	27192	59
60	20280	0	17349	24300	0	20808	28380	0	24276	32400	0	27734	60

Figure 21
Table of Distances for Course S1

ing point. The Indicator has been used in daylight, night and fog with uniform satisfaction. No retardation has been experienced, even when steering course S3, as shown by Sanborn Speed Indicator, although some retardation is to be anticipated.

On the U. S. S. ——— three officers and three Quartermasters are skilled in the use of this instrument. When learning to steer with it, the bow of the vessel should be disregarded, as she is heading the same number of degrees to starboard of normal course as the lubber-line has moved to port of initial position. After short practice this fact becomes familiar and the bow of the vessel may again be regarded, as in ordinary steering. As the lubber-line movement on an "S" course is rarely over 60° to port or starboard of the axis line, the eye

could readily line up the lubber-line and compass-mark without the helmsman's changing his position. In the sailing ship days the helmsman was frequently obliged to move all round the compass with his rotating tiller wheel. The new reduced compass card with bent wire lubber-line enables one to bring into alignment the compass-mark and lubber-line even when the latter has rotated 180°.

16. THE USE OF THE AUTOMATIC COURSE INDICATOR AGAINST SUBMARINE ATTACK

One may now analyze the relative merits of the Automatic Course Indicator and the existing Zigzag charts, signal boards, dials, disks, and clocks. With every device save the Automatic Course Indicator, the compass-mark has to be changed for each Zigzag leg. With the Indicator the same compass-mark is retained. If an error is made under the old system that fact remains unknown perhaps until the next azimuth is taken, and in any event it cannot be corrected without great trouble. With the Indicator the error simply cannot take place if the helmsman keeps the compass-mark in line with the lubber-line. If an interruption occurs and it is desired to zigzag in a different direction, in the present practice another chart of departures from the new normal direction has to be prepared and posted. With the Indicator the new normal compass-mark is told to the helmsman and the Zigzag or "S" course in the new direction proceeds at once. If an interruption occurs while the vessel is on a Zigzag course leg, the officers of the vessel have now to enter into a series of calculations to determine where the ship was when she abandoned the Zigzag. With the Automatic Course Indicator the direction the ship is heading at any given moment is shown on the Course Chart corresponding to the cam used, while in the Table of Distances in the column corresponding to the ship's speed is shown the distance reached along the Zigzag or "S" course, the distance away from the normal straight course and the distance along the normal. All desired data for dead reckoning are calculated in advance. In order to turn a course corner with the requisite slowness the helmsman now abandons a compass-mark and has none to rest his eyes upon until the new compass-mark is reached. With the Indicator he always has a lubber-line and compass-mark to look at, no matter what curve he is on or what course corner he is turning.

It should be noted that few vessels are now fitted with compasses whose card is divided into 360° marks. Some have four 90° quadrants. Many have no degree marks at all. Nearly all merchant ships are steered using compass points, half-points and quarter-points only. Since on a magnetic compass a degree mark is often too fine a line to be steered by, save with a magnifying glass, a quarter-point is the closest compass division used in most practice. When an order is given to turn a certain number of degrees, in the attempt to do so an error of sometimes over a degree is often made, since the nearest compass quarter-point mark rarely coincides with the required degree-mark. In the two tables given below the courses marked with asterisks do not correspond exactly with the degrees of turn desired. For example, under the present practice, if a ship headed NW ¾ N were ordered to turn 35° to port, the degree-mark to which the turn should be made is located between two compass-

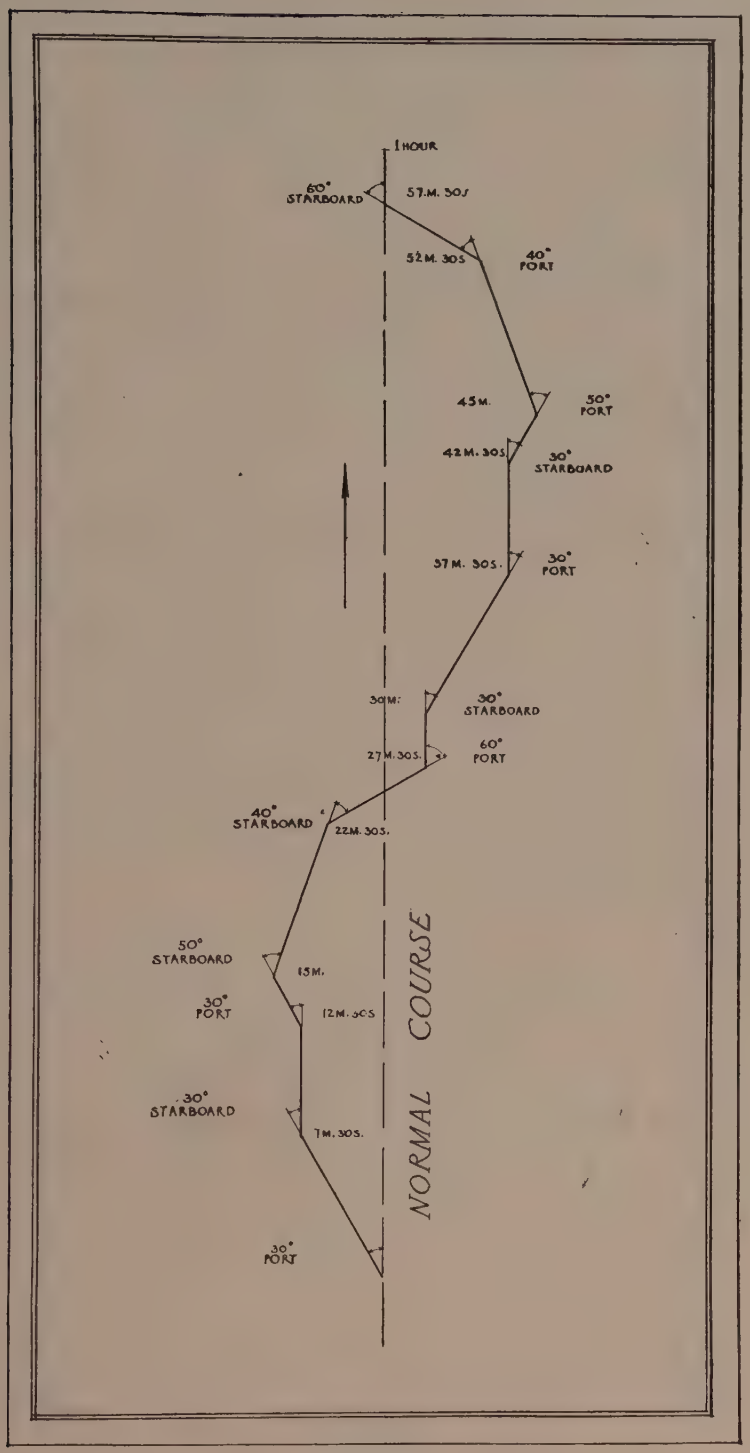


Figure 22
A Twelve Turn One Hour Zigzag of 1918

marks, WNW ¼ N and WNW ½ N,—slightly nearer the first. Should the order be given to steer WNW ½ N, the vessel would not return to position at the end of the Zigzag and, if in a convoy, the formation would speedily become confused. If a turn is made to port when it should be to starboard, or vice versa, the manoeuver system is thrown into an almost inextricable tangle. Numerous errors are likely to occur when helmsmen are required to change compass-marks hundreds of times on a journey. Is it any wonder that captains are loath to zigzag, as required, at night and in misty weather, even when approaching the most hazardous part of the danger-zone near shore? A single serious error or an accumulation of small errors may cause the vessel to run on the rocks. With the Automatic Course Indicator, since the alterations in course are accurately plotted on the cam, no such errors can arise. With this apparatus, a quarter-point or other compass-mark is used and is lined up with the plainly visible lubber-line.

Two examples will suffice to show the complexity of the present system of changing compass-marks in order to zigzag and the simplicity of the use of the Automatic Course Indicator, which can run Zigzags or "S" courses and whose compass may be used in the old way or with the Indicator. Figure 22 shows a typical Zigzag somewhat similar to those which under the present rules are to be completed in an hour. To steer the above the old way the following chart has to be used, with or without a bell or light signal:

			Straight Normal Course NNE (22°30′)
Time 0m	Turn	30° Port	Change Course to N ¾ W* (352°30′)
7m30s	"	30° Starboard	Change Course to NNE (22°30′)
12m30s	"	30° Port	Change Course to N ¾ W* (352°30′)
15m	"	50° Starboard	Change Course to NE ¼ N* (42°30′)
22m30s	"	40° Starboard	Change Course to E ¾ N* (82°30′)
27m30s	"	60° Port	Change Course to NNE (22°30′)
30m	"	30° Starboard	Change Course to NE ¾ E* (52°30′)
37m30s	"	30° Port	Change Course to NNE (22°30′)
42m30s	"	30° Starboard	Change Course to NE ¾ E* (52°30′)
45m	"	50° Port	Change Course to N ¼ E* (2°30′)
52m30s	"	40° Port	Change Course to NW ¾ N* (322°30′)
57m30s	"	60° Starboard	Change Course to NNE (22°30′)
60m	"	30° Port	Change Course to N ¾ W* (352°30′)

On the other hand, to steer this with the Automatic Course Indicator the order is merely "Use Cam No. X, Steer NNE";—the Zigzag is done automatically with NNE as the straight normal course. With the old system, to steer this typical Zigzag through the danger-zone for four days would require 1,152 changes in compass-mark. With the Automatic Course Indicator it would require no changes in compass-mark in four days and the use of only one Cam, Cam No. X. Today zigzagging is required for the whole voyage, so the comparison is even more striking.

It is the practice to change mean or normal course two or three times a day. With the Automatic Course Indicator, all that is needed is to tell the helmsman the new normal. The apparatus is kept running. The time of change in normal is recorded and the position fixed from the Course Chart and Table of Distances. If the cam of the Indicator is set to rotate once in every two, three or four hours, the compass-mark need not be changed at all during these hours. A

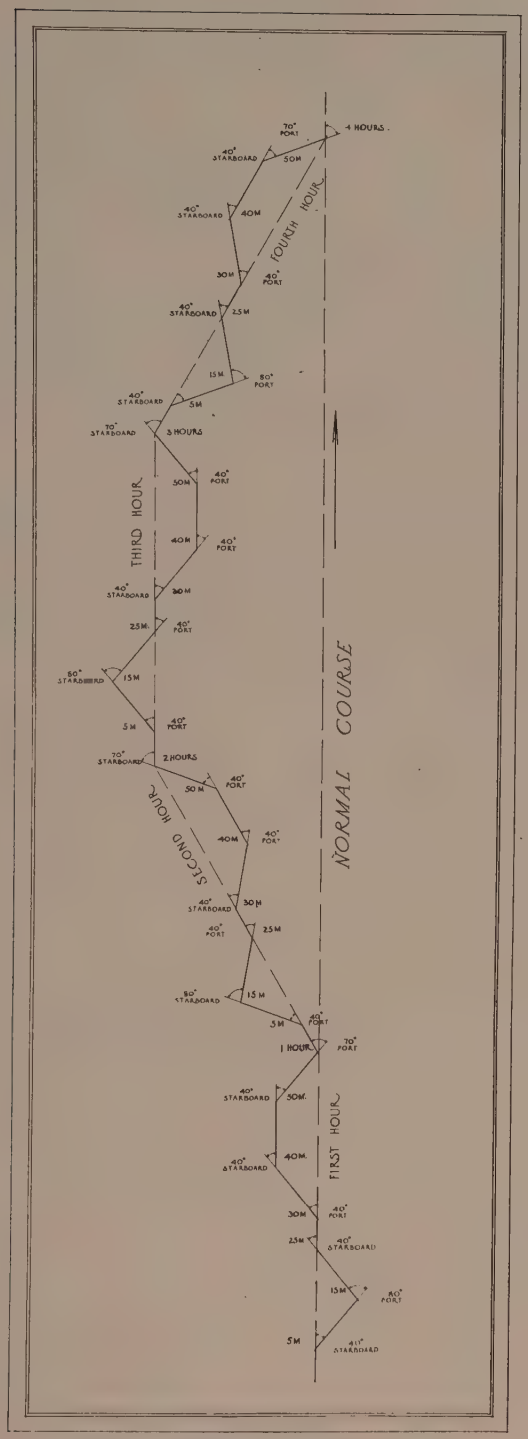


Figure 23
A Four Hour Zigzag of 1918 with Change in Normal Course Every Hour

typical Zigzag with a change in normal course every hour is shown in Figure 23. The following table gives the changes in compass-mark necessary to perform this in the old way:

Time (1st hour)				
0m				Straight normal Course ENE ¼ E (70°18′45″)
5m	Turn	40°	Starboard	Change Course to ESE ¼ E* (110°18′45″)
15m	"	80°	Port	Change Course to NNE ¾ E* (30°18′45″)
25m	"	40°	Starboard	Change Course to ENE ¼ E (70°18′45″)
30m	"	40°	Port	Change Course to NNE ¾ E* (30°18′45″)
40m	"	40°	Starboard	Change Course to ENE ¼ E (70°18′45″)
50m	"	40°	Starboard	Change Course to ESE ¼ E* (110°18′45″)
60m	"	70°	Port	Change Course to NE ½ N* (40°18′45″)
(2nd hour)				
5m	"	40°	Port	Change Course to N* (18′45″)
15m	"	80°	Starboard	Change Course to E ¾ N* (80°18′45″)
25m	"	40°	Port	Change Course to NE ½ N* (40°18′45″)
30m	"	40°	Starboard	Change Course to E ¾ N* (80°18′45″)
40m	"	40°	Port	Change Course to NE ½ N* (40°18′45″)
50m	"	40°	Port	Change Course to N* (18′45″)
60m	"	70°	Starboard	Change Course to ENE ¼ E (70°18′45″)
(3rd hour)				
5m	"	40°	Port	Change Course to NNE ¾ E* (30°18′45″)
15m	"	80°	Starboard	Change Course to ESE ¼ E* (110°18′45″)
25m	"	40°	Port	Change Course to ENE ¼ E (70°18′45″)
30m	"	40°	Starboard	Change Course to ESE ¼ E* (110°18′45″)
40m	"	40°	Port	Change Course to ENE ¼ E (70°18′45″)
50m	"	40°	Port	Change Course to NNE ¾ E* (30°18′45″)
60m	"	70°	Starboard	Change Course to E by S* (100°18′45″)
(4th hour)				
5m	"	40°	Starboard	Change Course to SE ½ S* (140°18′45″)
15m	"	80°	Port	Change Course to NE by E ¼ E* (60°18′45″)
25m	"	40°	Starboard	Change Course to E by S* (100°18′45″)
30m	"	40°	Port	Change Course to NE by E ¼ E* (60°18′45″)
40m	"	40°	Starboard	Change Course to E by S* (100°18′45″)
50m	"	40°	Starboard	Change Course to SE ½ S* (140°18′45″)
60m	"	70°	Port	Change Course to ENE ¼ E (70°18′45″)

The same Zigzag may be steered with the Automatic Course Indicator by giving the following order at the beginning of the 1st hour: "Use Cam No. Y. Steer ENE ¼ E." At the beginning of the 2nd hour the order is given "Steer NE ½ N." At the beginning of the 3rd hour the order is given "Steer ENE ¼ E." At the beginning of the 4th hour the order is given "Steer E by S." The simplicity of the new method is manifest.

17. THE APPLICABILITY OF THE AUTOMATIC COURSE INDICATOR TO VESSELS IN CONVOY

Convoy confusion arises chiefly from incorrect or inaccurate zigzagging, from differences in the turning circle of vessels, and from differences in speed. Confusion arises especially when a change of course in ordered. To give such an order the flagship has to signal at measured intervals: "Stop zigzagging," "Steer NE by E," "Start zigzagging." Some ships get all the signals on time, others get only some of the signals and late, still others occasionally fail to receive them at all. In view of the physical difficulties of marshalling and issuing orders to thirty odd ships scattered over a large area, the confusion incident to the present convoy practice is self-evident.

It is highly desirable, in view of the whole situation, to provide means whereby, with equal safety against U-boats, fewer vessels need proceed in convoy, and whereby those that still seek such protection may manoeuvre with greater assurance and may avoid as many as possible of the serious disadvantages of group-movements. This would release many war vessels for the aggressive anti-submarine campaign and would also allow lower marine risk insurance premiums to be charged. The Automatic Course Indicator will notably ameliorate conditions, both by enabling the faster ships to proceed alone or with escort only and by facilitating the precautionary manoeuvres of ships remaining in convoy. Vessels steering an "S" course, with a speed exceeding 10 knots (the usual maximum practical submerged speed of a submarine), will be sufficiently secure to justify them in proceeding alone, even if they could go in convoy, provided they have gun armament equally or nearly as heavy as that carried by U-boats.

The Automatic Course Indicator will minimize convoy accidents by facilitating and rendering more exact precautionary manoeuvres. For instance, instead of requiring three orders to secure a change of mean course on a Zigzag, one alone (the time and direction of the new course) is involved. Thus the most crucial and dangerous manoeuvre of a convoy is simplified and safeguarded. Of the three chief causes of convoy confusion enumerated above, the Indicator will eliminate the first and second. As the instrument shows the correct direction of the Zigzag or "S" course turn and the angle, the convoy confusion due to incorrect or inexact zagzagging will be eliminated. The Indicator corrects the differences in the turning circles of vessels, because so long as the compass-mark is kept opposite the lubber-line, the axis of the vessel is at the correct angle to produce the turning circle prescribed. Errors due to speed differences cannot be removed by any known means, as convoy confusion due to differences in speed of ships is inherent in group navigating. The slower vessels have to "clip" the Zigzag to regain or hold position. With the Indicator this will still have to be done, but when back in position the Zigzag or "S" course will be picked up with full knowledge of the amount and time of the next change in angle. Furthermore, as there is less retardation on an "S" course than on a common Zigzag there arise less variations in actual speed.

For these several reasons the Automatic Course Indicator will secure better and more accurate zigzagging than can be now steered by a convoy. It will also enable a convoy to steer an "S" course, provided all the ships are so equipped. The equipping of all the ships is an easy and inexpensive matter and the installation is a matter of a few hours. As an "S" course is superior to a Zigzag in safety, speed and distance-made-good, one can justly claim that the Indicator will lead to a considerable improvement in convoy practice and efficiency. British convoy experts who saw the Indicator in use on the U. S. S. ——— in Long Island Sound declared that if the instrument had existed and been installed on ships before the war, a large proportion of their destroyed merchant fleet would still exist.

The use of the Indicator by a ship in convoy is not contingent upon its use by the other vessels save in regard to steering "S" courses. Zigzags may

be steered in the old way or in the new way whether the other ships are so equipped or not. If it is desired not to rotate the lubber-line, the cam may give, if desired, a bell signal for each Zigzag turn. The bell rings the number of the turn in the hour course. The Admiralty and McGray clocks do not do this. Their bells ring only once each turn. If it is desired to Zigzag in convoy using the method or rotating the lubber-line, the cam corresponding to the Zigzag selected from the list, provided for that purpose, enables the vessel fitted with the Indicator to make the same Zigzag as the others. The ship equipped will do it with more exactness and less inconvenience than that un-equipped.

This terminates the study of the sinuous course and the Automatic Course Indicator in relation to submarine matters. While the U-boat compaigns have been the absorbing events of the naval war, there have been several notable sea fights between fleets. Jutland is the leading naval action. There have also been frequent contests between warships and coast defenses. Gallipoli and Zeebrugge are the most important of these. Attempts to evade search-lights have also been numerous, as at Pola. Although there has been in these actions less opportunity for irregular course navigation, there has been sufficient experience to indicate its great role in future naval contests. To determine the utility of "S" courses in this field, elaborate tests were necessary, as human experience was not so fully educated as in the case of submarine attack.

18. THE USE OF THE AUTOMATIC COURSE INDICATOR BY WARSHIPS IN BATTLE

In July, 1918, in cooperation with the military authorities, the Automatic Course Indicator on the U. S. S. ——— was employed in special manoeuvres before certain coast fortifications. It was found that the observers in the forts, using a horizontal and also a vertical base line, were able to plot with reasonable accuracy an "S" course with observations made every thirty seconds and at close range. Figure 24 shows how beautifully the ship steered the sinuous course. The course was plotted while the vessel was proceeding at 15 knots from 5,000 to 12,000 yards range. After 12,000 she could be plotted with difficulty and with inaccuracy. The observers were, however, unable to locate with precision the proper prediction points and set-forward points for big-gun and mortar fire at any range.

Mortars are the main coast defense reliance. It is publicly known that they are generally fired in view of three observations, taken at 0 seconds, 30 seconds and 1 minute. The angles and ranges noted on these occasions are used, with corrections, to locate the so-called "prediction point" at the 2nd minute and the "set-forward point," which adds the time of flight of the projectile. In the case of mortar fire, with its high trajectory, this is between 45 seconds and one minute for most ranges. It is the practice to calculate, therefore, for mortar fire, the future position of a vessel from one and three-quarters to two minutes ahead. On a straight course the prediction and set forward points come close to the vessel's actual course. Figure 25 shows this fact for ranges between 8,000 and 9,000 yards. Inspection of the results shows an aver-

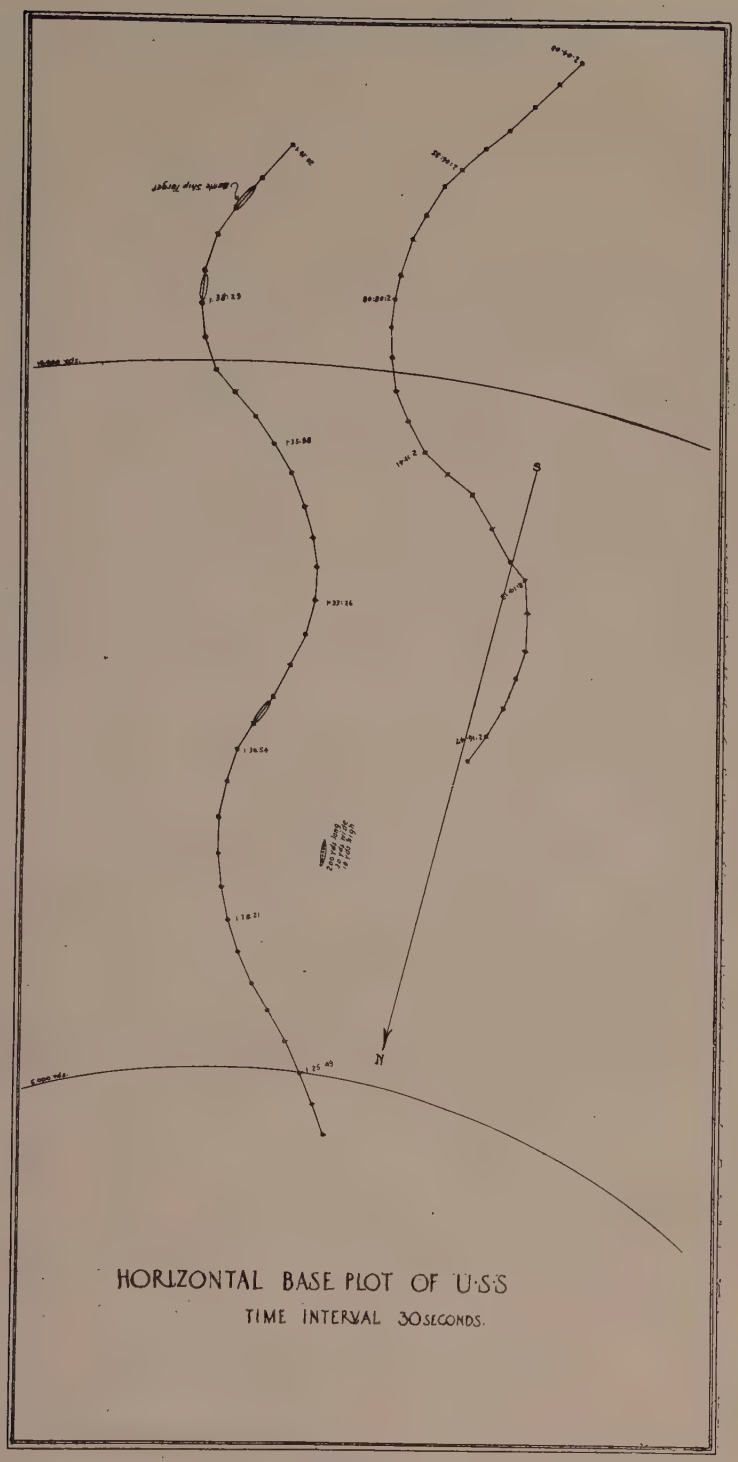


Figure 24
Portions of S3 Course Steered by the U. S. S. ———.

age error of 35 yards. In regard to sinuous courses at the same range one finds for course S 1 an average range error in the set-forward point of about 90 yards in range and 15 yards in deflection. On inspecting Cam 3 course one finds the errors are very great in the determination of the set forward point. The Cam 3 course run at 8,000 yards range shows average errors in the location of the set-forward point of 175 yards longitudinally and 110 yards literally. These errors are what may be ordinarily expected in mortar firing at a vessel steering an "S" course. The sinuous course causes a loss in hitting power of mortar batteries of about 50%, so that only high velocity rifles should be used in future installations, confining the use of mortars to special cases. The result of these tests demonstrated the vulnerability of coast defenses armed with mortars when bombarded at long range by warships steering a sinuous bombardment curve. As a result of the invention of the Automatic Course Indicator the firing system and armament of coast defenses will have to be radically revised.

In regard to gun fire, a lesser but very material error is introduced. In the case of 12" guns the prediction interval is only 30 seconds and time of flight from 15 to 30 seconds. The error appears to be proportional or nearly so to the time interval at which the future position of the ship on the "S" course must be guessed. On a straight course the average error in the set-forward point is about 24 yards. With the target head-on when steering an "S" course, at ranges between 7,000 and 12,000 yards, the total probability of hitting is reduced by 25% and with the target broadside the sinuous course at 8,000 yards range reduces the longitudinal probability of hitting about 10%. At the longer ranges, 18,000 and 21,000 yards, the sinuous course will give an attacking fleet more immunity than now from rifle fire. When spotfiring is resorted to the error will be far greater even than that indicated above.

The importance of these tests at Fort X cannot be too strongly emphasized. As the mortar and gun fire from a land battery having a long horizontal and high vertical base line, at 8,000 yards range, was seriously affected, how much more will be the effect upon gun firing between battle fleets at 18,000 yards range which resort to spotfiring! A fleet on an "S" course will be much more immune from the enemy's guns, while her own control officers, knowing the "S" course, can alter their ship's fire as the curve changes. The Table of Distances and Angles corresponding to the "S" course used will show the allowances to be made for changes in range and angle at a future moment. One's own firing may be affected, but nowhere nearly so much as the opponent's.

Rear Admiral Bradley A. Fiske, U. S. N., has carefully analyzed the practice of spotfiring and range finding from warships, and, with reference to the effect of an irregular course upon firing efficiency. He says:

> "The danger of depending upon spotting alone may be seen when we recognize the fact that, if the enemy has good range finders, and if the enemy's Admiral, after the fleets are drawn up in parallel columns, will carry out the well known 'follow-the-leader' tactics, changing the course of the leader back and forth, say one point each side of the middle course, he will change the range irregularly and frequently, back and forth, about

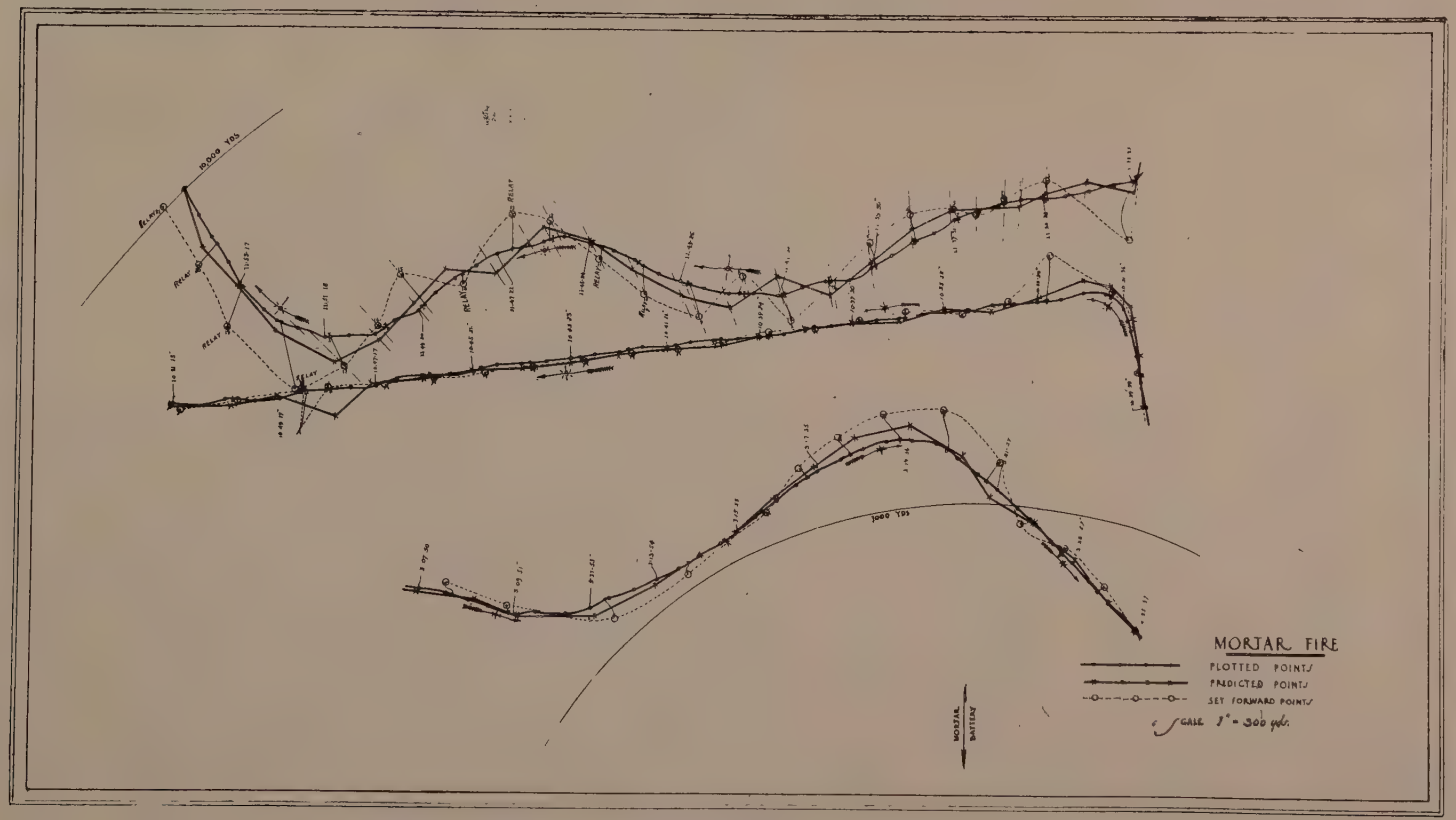


Figure 25
Plot of Mortar Fire from Fort X Against the U. S. S. ——

93 yards a minute; the fleet speed being supposed to be 15 knots. The gradual changes of course and distance will not bother the enemy's range finders, so they can keep our range all the time, but on our lofty and exposed fire-control platforms, our armies of spotters, change-of-range projector-men, and the telephonists will not be able to find and transmit correctly the sight bar range." ("The Mean Point of Impact," Rear Admiral B. A. Fiske, U. S. N. Proceedings U. S. Naval Institute, Vol. 38, September, 1912, page 1004.)

To get a clear idea of the importance of estimating correctly the mean point of impact, Admiral Fiske assumes the case of two hostile fleets meeting in battle, these fleets otherwise equal and having gun pointers of equal skill, but one fleet, A, having a means of getting the sight bar range at 10,000 yards with an average error of only 50 yards (no matter what the means may be), the other fleet, B, having means whereby the error is 100 yards. In this case, if the gun pointers are well trained, and the weather good, the mean vertical deviation would be only about 20 feet, and "A would hit B two and one-half times as often as B would hit A" (Op. Cit. P. 1001). If A has a means by which its sight bar range is 100 yards wrong, while B's is 150 yards wrong, "A would hit B five times as often as B would hit A." Or if A has a system whereby he gets the sight bar range with an error of 50 yards, while B's error is 150 yards, "A would hit B twelve and one-half times as often as B would hit A." If, therefore, in addition to the usual errors in gunfire from a war vessel, there is added the error due to the opposing vessel's being on a variable "S" course, the result may easily mean defeat for the fleet on a straight or Zigzag Course. The "S" course is the final outgrowth of the Zigzag 'follow-the-leader' tactics.

The Battle of Jutland furnishes a striking illustration of the accuracy of these conclusions. It is widely known that the Germans zigzagged frequently, but on what system there is no evidence. We know, however, that they zigzagged on short legs. The control officers on English ships experienced difficulties, and, generally speaking, the rate or mean point of impact was in error due to the manoeuvres of the Germans. During occasional intervals the rate was accurate and hitting was established for a short time. This was presumably when the Germans were on a straight leg of their Zigzag. The system of continuously altering course defeats any system of fire control based on rate-finding for the reason that by the time the plot has established a rate it is no longer applicable. The rate of spotting is not sufficiently rapid to give the necessary indications as to changes in course. On the other hand, alterations of course by the British did not hamper their own control and director layers to any great extent. In any event, gunnery must adapt itself to meet the requirements of tactics. The Battle of Jutland showed, among other things, the necessity, first, of accurate and early hitting, and, second, of the use of defensive tactics to avoid being hit. It is imperative for ships to repeatedly slightly alter course for defensive purposes.

Ships heretofore have been able to Zigzag only, but the Automatic Course Indicator enables them to steer a sinuous course. This will permit a ship to

get in the first salvo against a vessel not so manoeuvering. The hostile vessel will take longer to get the mean point of impact and when it has established a rate, will be unable to hold it. As less than one shot in a hundred reached its mark at Jutland where ships were zigzagging, it is clear that marksmanship against a vessel on a sinuous course having no straight legs will be even less accurate. To nullify even partially the effect of sinuous courses on gunfire, it will be necessary for coast defenses and warships to fire at an area rather than at an individual vessel. The object would be to lay a barrage in the zone within which the set-forward point must be located. This involves a radical modification in naval firing-practice, also a greater expenditure of ammunition and an increase in the number of guns used; new factors which cannot always be provided.

The Automatic Course Indicator will allow the most complicated fleet manoeuvres to be undertaken at a single signal from the flagship. With the new divisional independence recently introduced in naval warfare there will be a far greater field for manoeuvering than heretofore. The "S" course comes at a happy moment in view of the recent tactical changes. The fleet "turning point" may be eliminated and yet the ships return to station in line at the appointed time or place. This facility means that the enemy cannot concentrate fire on the "turning point" and damage each vessel in turn as she follows a change in the fleet's or division's normal course. Ships of a division may navigate at different ranges and on different curves, and yet be moving in synchrony. Fleets may enter into action and close range on a curve. It is essential for the Great Powers to keep pace with the latest navigation developments and to adapt their gunnery and naval tactics to the sinuous course.

19. THE USE OF THE AUTOMATIC COURSE INDICATOR FOR NAVAL SCOUTING

The task of war vessels in their search for enemy cruisers will be facilitated and rendered more effective by enabling them to steer accurately any desired scouting curves. The "Search Curve" is defined as follows by Commander Harry S. Knapp, U. S. N., and Lieutenant Commander George W. Logan, U. S. N.:

> "This curve represents the track of a scout seeking an enemy that has at a known time left a known place and has steamed at an assumed speed upon an indeterminate though constant course." ("Useful Curves, Scouting and the Torpedo Danger Area," Com. H. S. Knapp and Lt. Com. G. W. Logan, 1908, p. 13.)

Figure 26 furnishes an illustration of a very simple "Search Curve." The distance A B is taken as 90 miles and the scout and enemy are supposed to start simultaneously, the former from A and the latter from B, at speeds of 20 and 10 knots, respectively. This single ship "Search Curve" is approximately 2,100 miles long. If two scouts conduct the search, starting together from A and separating at C, each going on a different side of the line A B, the distance steamed by each from A to D will be only 350 miles. The "Retiring Search

Curve" is the "Search Curve" modified for darkness, fog, and bad weather, and applied to a number of scouts in such a way as to enable them to search thoroughly a given area by co-ordinating their work.

In submarine hunting various modifications of the search curve in small scale may be used by the destroyers and patrol boats. At night it is especially hard to steer a curve, without constantly getting off the exact course. Since it

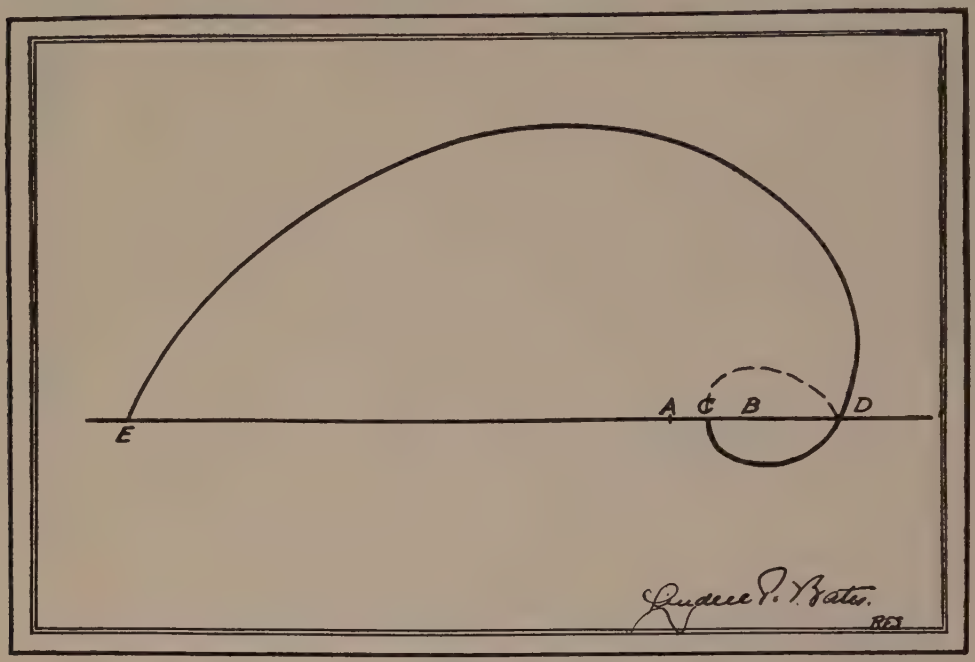


Figure 26
Typical Naval Search Curve

is during darkness, when visibility is very low, that the submarines rise to recharge their batteries, the new ability to steer an exact curve which is given patrol boats by the Automatic Course Indicator will be of particular utility. It takes some time to plot such a curve for present steering. A selection of search curve cams may readily be prepared in advance, for use in daylight, night or fog. These curves may be completed in any desired period of time.

20. THE USE OF THE AUTOMATIC COURSE INDICATOR TO EVADE SEARCHLIGHTS

Tests were made at night off Fort X to determine whether steering an "S" would enable a vessel to evade or throw off the Fort's searchlights, the most powerful known. On a clear night the U. S. S. ——— proceeded between Point Y and Island Z at 8,000 yards mean range on an "S" course until opposite the end of the latter and then went straight through a channel at a distance of about 3,000 yards from the nearest searchlight. Although the approx-

imate time of her departure was known, she passed through all five searchlights wholly undetected and was picked up only when, after passing through the channel, she turned on her own lights. This was repeated on another occasion with the modification that she left a known point at a known time and followed a known mean course. She was located at 8,000 yards for three minutes, then she was lost and was not seen again until within 4,000 yards of the end of her forty-minutes' journey, and when 2,000 yards away from the nearest searchlight. A factor which aided the ship in escaping the beam was the sinuous course. On the last night she was picked up in the beam of No. 4 light. No. 3 covered No. 4, and she was held intermittently for about two minutes. No. 3 then uncovered and she was held intermittently in the beam of No. 4 about one minute, at which time the "S" course evidently swerved north-east during one of the momentary eclipses, and the eclipse became permanent until she suddenly loomed up in the beam of No. 4 at about 2,000 yards off shore. At this range, of course, she was followed without difficulty. The Automatic Course Indicator helped the vessel to evade searchlights. Since most bombardments of coast defenses will occur at night in the future, as at Zeebrugge, this increased immunity will be of notable advantage to the attacking fleet. Shore defenses as now armed will be well nigh helpless against long range bombardment at night by warships steering a sinuous bombardment ellipse.

21. CONCLUSION

The submarine is a factor which will be present in naval warfare for all time. Although the German coast line is more susceptible to blockade by warships, nets and mines than that of any other Great Power, the U-boats have been able to conduct a campaign which at one time came perilously close to success and which is even to-day an extreme annoyance. Figure 27 reproduces a German official propaganda map showing ships sunk during the first year of unrestricted U-boat warfare. About three hundred and fifty American naval ships of all kinds and numerous aeroplanes in eighteen months of arduous, aggressive and defensive efforts have destroyed only about nine submarines. Our record is proportionately at least equal to and probably better than the British. All that human skill and devotion could bring to bear were given unreservedly. Supreme praise belongs to the officers and men for the achievement of even nine destroyed submarines, but the stupendous money cost, direct and indirect, beggars statement. The war has certainly demonstrated that all scientific means of defense and attack must be utilized to meet the submarine.

It has been an axiom of the problem of the defense of vessels against gunfire and torpedo attack that nothing shall be placed upon a ship which diminishes her speed or manoeuvering power. The only means, so far practically developed for protective purposes, are armament, zigzagging, camouflage and smoke boxes. The first two are the main reliance, as the efficiency of the two latter is small. Smoke screens can very rarely be utilized, and camouflage effectiveness depends upon many variable factors. Merchant ships today even are for the most part less well armed than U-boats, so that precautionary manoeu-

Figure 27

"England's Distress," According to a German Map Showing Location of Ships Sunk in One Year

vers alone can be a constant reliance. It is in the direction of perfecting existing means of defense that one may anticipate the best results. The way to perfect the Zigzag is clear. The perfected Zigzag is the spiral "S" curve.

The "S" course adds to a ship's safety, enables her to make better speed than when zigzagging and permits a greater distance towards port to be made good. It places the greatest possible difficulty in the way of the submarine's approach to a torpedo-firing position and to attack with torpedo or gunfire. There is no way to steer an irregular curved course without the Automatic Course Indicator, so that to give ships the best chance of survival its adoption is essential. The Indicator may be used on merchantmen or war vessels, proceeding singly, with escort, in fleet or in convoy. It may be adapted to the magnetic or gyroscopic compass. With it we may steer Zigzags without moving the lubber-line, in the old way, or moving the lubber-line, in the new way. In the new way one may also steer "S" courses, search curves, bombardment circles and other manoeuvres. For the first time since the Chinese invented the compass, about two thousand years ago, the method of steering a vessel by it is changed. A movable lubber-line automatically rotated according to a predetermined course is used instead of the traditional fixed lubber-line. The Automatic Course Indicator has come into the world to stay.

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